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AFE 75 COTS AEH Issues and Emerging Solutions Final Report

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16. Abstract

This report, based on global industry and regulatory expert experience and knowledge, shows the tip of the COTS AEH issues iceberg, and provides possibilities for COTS AEH solution development including: 1) use of existing standards and guidance documents as a structure for future evolution of COTS Standards, 2) possible future COTS standards to implement this structure, 3) need for combined industry/regulatory/manufacturing research to develop COTS AEH issue mitigations including the development of COTS standards and guidance, 4) mechanisms to shortcut the slow evolution of standards, 5) a candidate structure for relevant and emerging COTS standards linked to evolving development assurance standards, and 6) identification of standard bodies responsible for the implementation of the ongoing COTS solution(s). All organizations and individuals who work with COTS AEH in avionics are encouraged toread and understand this report, and those who address these COTS AEH issues should use AFE 75 research approach and results to work them.

This report provides a COTS AEH Assurance Framework including a common structured approach to evaluate COTS AEH issues. It is applied to the 22 issues addressed in this report and is recommended for application to future issues not addressed herein. This approach is presented in a manner that supports development of project-level COTS AEH mitigations that can be rolled into development design assurance and a practical compliance solution to FAA Engineers and delegates, and to Standards administrators. This Report (1) provides a stand-alone treatment of each issue and a five-step suggested evolution of COTS and development assurance standards and guidelines. This research (1) provides detailed technical information about the issues; (2) introduces research required to provide new knowledge needed to implement solutions for the COTS AEH issues; (3) explores required tools, standards and guidance needed for COTS-based systems development assurance, certification, and maintenance; and (4) considers certification and assessment criteria and methods for the given issues. This structured approach may be used to evaluate and work emerging COTS AEH issues. This AFE 75 report addresses design, component selection, development assurance, and certification issues for AEH COTS electronics product items such as hybrids, multichip modules, microprocessors, field-programmable gate arrays, application-specific integrated circuits, and small assemblies including printed wiring assemblies and disk drives.

17. Key Words

COTS AEH, COTS in AEH, commercial-off-the-shelf, COTS, airborne electronic hardware, AEH, avionics, aircraft certification. regulatory standards and guidance, system qualification, aircraft safety, avionics safety, hybrids, multichip modules, microprocessors, FPGAs, ASICs, integrated circuits, COTS assemblies, derating, uprating, sparing reliability, CMOS, single event effects, SEE, atmospheric radiation, limited life semiconductors, reliability, lead-free electronics, errata, counterfeit parts, undocumented features, electronic supply chains, usage, production, intellectual property, IP, unknown changes, embedded controllers, packaging and mounting, obsolescence management, compliance, design assurance, system on chip, SoC.

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Table of Contents

List of Figures

List of Tables

AFE 75 Final Report Composite Acronyms and Abbreviations List

AC	Advisory Circular
ACI	ACI Technologies, Inc.
ADHP	Aerospace, Defense, and High Performance
AEH	Airborne Electronic Hardware
AFE	Authorization for Expenditure (for AVSI Projects)
AFE 17	Methods to Account for Accelerated Semiconductor Wearout R&D Project
AFE 43	Selection and Evaluation of Microprocessors for Critical Airborne Systems R&D Project
AFE 70	Integrated Reliability Processes R&D Project
AFE 71	Reliability Prediction Software R&D Project
AFE 72	Mitigating Radiation Effects R&D Project
AFE 80	Integrated Reliability R&D Project
AFE 83	Semiconductor Reliability R&D Project
AFO	Overall Acceleration Factor
AFT	Temperature Acceleration Factor
AFV	Voltage Acceleration Factor
AIA	Aerospace Industries Association
ALU	Arithmetic Logic Unit
AMC	Avionics Maintenance Conference
ANADEF	ANAlyse de DEFaillance , French Association specializing in failure analysis
AND	AND Logic Operation
ANSI	American National Standards Institute
APMC	Avionics Process Management Committee
AQEC	Aerospace Qualified Electronic Components
AR	Aviation Research
ARP	Aeronautical Recommended Practice
AS	Aerospace Standard
ASD	AeroSpace and Defense Industries Association of Europe

ASIC	Application-Specific Integrated Circuit
ASSP	Application Specific Standard Product
ATC	Air Traffic Control
AVSI	Aerospace Vehicle System Institute
BIST	Built-In-Self-Test
C	Centigrade
CA	California
CAF	Conductive Anodic Filament
CALCE	Center for Advance Life Cycle Engineering (Univ. of Maryland)
CAMP	COTS Assembly Management Plan
CEH	Complex Electronic Hardware
CM	EASA Certification Memorandum
CMOS	Complementary-Metal-Oxide-Semiconductor
CNES	Centre national d'études spatiales (National Centre for Space Studies)
COTS	Commercial-off-the-Shelf
COTS AEH	Airborne Electronic Hardware available as Commercial-off-the-Shelf
COTS in AEH	COTS components embedded in Airborne Electronic Hardware
CPU	Central Processing Unit
CRC	Cyclic Redundancy Code
CRI	Certification Review Item
CTE	Coefficient of Thermal Expansion
D&R	Design & Reuse
DDECS	Design and Diagnostics of Electronic Circuits and Systems
DED	Double Error Detection DRAM
DfR	DfR Solutions
DFT	Design For Test
DMS	Diminishing Manufacturing Sources
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DO	Document
DoD	Department of Defense

DOT	Department of Transportation
DRAM	Dynamic Random-Access Memory
DSP	Digital Signal Processor
DSPO	Defense Standardization Program Office
EASA	European Aviation Safety Agency
EC	European Council
ECC	Error Correcting Code
ECMP	Electronic Components Management Plan
ECSS	European Cooperation for Space Standardization
ED	EUROCAE Document
EDA	Electronic Design Automation
EDFAS	Electronic Device Failure Analysis Society
EEE	Electrical, electronic, and electromechanical (parts used in space systems)
EIA	Electronic Industries Alliance
EM	Electromigration
EMI	Electromagnetic Interference
eMMC	Embedded MultiMedia Card
EPC	European Passive Component
EPCIA	European Passive Component Industry Association
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FIDES	Latin Root of the French word “Fiabilité”, reliability in English.
FMEA	Failure Modes and Effect Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FPGA	Field-programmable Gate Array
FR-4	Circuit board material grade designator
FTA	Fault Tree Analysis
GAMA	General Aviation Manufacturer Association

GAO	Government Accountability Office
GEIA	Government Electronics and Information Technology Association
GHz	GigaHertz
GPD	Graceful Performance Degradation
H.R.	House Resolution
HB	Handbook
HCI	Hot Carrier Injection
HDBK	Handbook
HMI	Human Machine Interface
I/O	Input/output
IBM	International Business Machines
IC	Integrated Circuit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMAPS	International Microelectronics Assembly and Packaging Society
INST	Instructions
IP	Intellectual Property
IPC	Association Connecting Electronics Industries
IRPS	International Reliability Physics Symposium
ISCA	International Symposium on Computer Architecture,
ISTFA	International Symposium for Testing and Failure Analysis
JEDEC	Joint Electronic Device Engineering Council
JEPP	Joint Electronic Device(s) Engineering Council Publication
JESD	JEDEC Standard
JTAG	Joint Test Action Group
KNC	Knight's Corner
LCD	Liquid Crystal Display
LEAP	Lead-free Electronics in Aerospace Project
LRU	Line Replaceable Unit
MAC	Media Access Control

MBU	Multiple Bit Upset
MCFA	MultiCore for Avionics (Industry Group)
MeV	Million-Electron-Volts
MIC	Many Independent Core
MIL	Military
MMC	MultiMedia Card (flash memory card)
NAND	Not AND, i.e. negation of Logical “AND”
NASA	National Aeronautics and Space Administration
n/cm^2	Neutron Differential Flux
NBTI	Negative Bias Temperature Instability
nm	Nanometers
NSEU	Neutron Single Event Upset
NSWC	Naval Surface Warfare Center
OCM	Original Component Manufacturer
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
OSCI	Open SystemC Initiative
PAS	Publically Available Specifications
Pb	Lead
PBTI	Positive Bias Temperature Instability
PCB	Printed Circuit Board
PCIe	Peripheral Component Interconnect Express
PCN	Product Change Notice
PERM	Pb-free Electronics Risk Management
PHY	Physical Layer
PLD	Programmable Logic Device
ppm	parts per million
Q	Quality (of the ECSS Space Product Assurance Branch)
Q4	4th Quarter
R&D	Research & Development

RAS	Reliability, Availability, Serviceability
RoHS	Restriction of Hazardous Substances
RNC	Referential Normatif du CNES
ROM	Read-Only Memory
RTCA	Radio Technical Commission for Aeronautics
SAE	SAE International, Inc. (Formerly known as Society of Automotive Engineering, Inc.)
SCD	Specification Control Drawing
SD	Secure Data
SEB	Single Event Burnout
SEC	Single Error Correction
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SET	Single Event Transient
SEU	Single Event Upset
Si	Silicon
SIB	Safety Information Bulletin
SM	Surface Mount
SMT	Surface Mount Technology
Sn	Tin
Sn/Pb	Tin/Lead
SoC	System on Chip
SoCCER	SoC from Civilian to Armament Re-use
SOW	Statement of Work
SPE	Synergistic Processing Element
SPIRIT	Structure for Packaging, Integrating and Re-using IP within Tool-flows
SRAM	Static Random Access Memory
sRIO	Serial Rapid I/O
ST	Standard

STD	Standard
SW	Software
SWCEH	Software and Complex Electronic Hardware
$T_{ambient}$	Ambient Temperature
TB	Technical Bulletin
TC	Technical Committee
T_{case}	Maximum (outer case) temperature a component can stand
TDDB	Time Dependent Dielectric Breakdown
$T_{junction}$	Junction Temperature
TP	Technical Publication
TR	Technical Report
TS	Technical Specification
U.S.	United States
UAV	Unmanned Aerial Vehicle
UG	User's Guide
USA	United States of America
USB	Universal Serial Bus
UTE	French Standard
V	Volts
V&V	Verification and Validation
VHDL	VHSIC Hardware Description Language
VHSIC	Very High Speed Integrated Circuit
VLSI	Very Large Scale Integration
VME	Versa Module Europa
WCET	Worst Case Execution Time
WG	Working Group
µP	Microprocessor

Executive Summary

Use of commercial-off-the-shelf (COTS) airborne electronic hardware (AEH) is an inescapable necessity for aerospace vehicle development, but the rapid technological advance of COTS AEH products that are not designed for long-life, life-critical, stringent-environment applications (e.g., avionics) results in ever-growing problems and interacting issues. AFE 75 selected 22 current issues for consideration under this research task. These COTS issues are already being experienced in aerospace, defense, and high-performance system development. They are yesterday's (and tomorrow's) issues and the required standards, guidance, tools, and mitigation techniques are already late. Immediate action and rapid development are required. The project further considers proposed supplemental phases to continue work on COTS AEH issues and actions.

This report documents the results of the AVSI COTS AEH Assurance Methods Project (AFE 75), is based on global industry and regulatory expert experience and knowledge, shows the tip of the COTS AEH issues iceberg, and provides potential possibilities for COTS AEH solution development including: 1) use of existing standards and guidance documents as a structure for future evolution of COTS Standards, 2) possible future COTS standards to implement this structure, 3) need for combined industry/regulatory/manufacturing research to develop COTS issue mitigations including the development of COTS standards and guidance, 4) mechanisms to accelerate the slow evolution of standards, 5) a candidate structure for relevant and emerging COTS standards linked to evolving development assurance standards, and 6) identification of standard bodies responsible for the implementation of the ongoing COTS solution(s). All organizations and individuals who work with COTS AEH in avionics are encouraged to read and understand this report, and those who address these COTS AEH issues should use AFE 75 research results to work them.

This report provides a common structured approach for industry use to evaluate COTS AEH issues. It is applied to issues addressed in this report and is recommended for application to future issues not addressed herein. The approach supports development of project-level COTS AEH mitigations that can be rolled into development design assurance and provides a practical compliance solution to FAA Engineers and delegates, and to Standards administrators. This report provides a stand-alone treatment of each issue (Section 2), a five-step suggested evolution of COTS and development assurance standards and guidelines (Appendix B), and a comparison of the technological issues (Appendix C).

The AFE 75 research:

1. provides detailed technical information about the issues;
2. specifies research required to provide new knowledge needed to implement solutions for these issues;
3. explores required tools, standards and guidance needed for COTS-based systems development assurance, certification, and maintenance; and
4. considers certification and assessment criteria and methods for the given issues.

This structured approach is suitable for evaluating and developing solutions for emerging COTS AEH issues.

This AFE 75 report addresses design, component selection, development assurance, and certification issues for AEH COTS and COTS in AEH electronics product items such as hybrids, multichip modules, microprocessors, field-programmable gate arrays, application-specific integrated circuits, and small assemblies including printed wiring assemblies and disk drives. COTS electronics products are almost unanimously targeted for markets other than aerospace, and their designs, configuration control processes, qualification methods, and reliability assurance practices are developed and implemented without regard for the needs of aerospace users.

AFE 75 subject matter experts identified 26 categories of candidate issues unique to the incorporation of COTS electronics in aerospace systems design, and selected 22 issues to be addressed in this research. Some candidate issues did not meet the AFE 75 criteria for COTS issues and one (Intellectual Property) was beyond the resources available in the first AFE 75 phase. Each selected COTS issue was evaluated to determine their technical characteristics and their impact on aerospace design, component selection, implementation, validation, certification and life cycle maintenance. Special attention was given to the need for awareness of these issues by both industry and regulatory agencies to attain a "level playing field" based on consistent application of safety and reliability guidance, and mitigation of the risks associated with the issues.

Although both the commercial and military segments of the aerospace market are increasingly dependent on COTS, there is no aerospace consensus on methods to assure their safety and airworthiness in AEH, or on criteria to verify that those methods are used properly in design, production, or support. A major characteristic of the COTS electronics market is the rapidity with which it changes, and the regular emergence of new issues that can affect avionics safety and airworthiness. The COTS issues identified in this report are seen as a baseline set of issues. They may be modified as needed and additional issues may be added in the future. This report explains how the issues can impact safety and airworthiness of aircraft, and how they can be addressed in the certification process. To the extent possible, existing industry handbooks, standards, reports, and technical publications are leveraged in recommended design guidance document structure (Appendix B), and in future work beyond the scope of AFE 75. Where additional knowledge is required, research to produce that knowledge and the candidate responsible organizations are identified.

The nature of the COTS challenge is that the methods to demonstrate safe application of COTS AEH within the certification process are difficult, if not impossible, to define in any objective way. Furthermore, the methods that might be used are likely to be expensive and time-consuming. Consensus is necessary within the aerospace industry and regulatory agencies regarding the methods, documents, and tools to be used in the development assurance and certification processes, and the criteria and methods to verify compliance.

The results of this report are designed to be actionable including the detailed descriptions and recommendations for the 22 issues, the roadmap for the development of COTS AEH standards

and guidelines, and the structured approach for the evaluation of COTS AEH issues. These results further offer a baseline for industry and regulatory action to achieve implemented solutions for current and future COTS AEH issues.

Future system/aircraft development projects will need to address COTS AEH issues. Some of these COTS issues will be beyond the resources of a single project or a single development organization. This project demonstrates that the Aerospace Vehicle Systems Institute (AVSI) is a viable research environment to enable multiple industry and regulatory partners to address those COTS issues too large, complex, and unresolved to be addressed by single projects or single organizations. Aerospace management must become aware of the serious nature and scope of COTS AEH issues and support the communal research necessary to avoid project roadblocks, achieve required safety, and avoid potential liabilities and mitigate risks associated with breaches of operational safety.

1. Introduction

Use of commercial-off-the-shelf (COTS) airborne electronic hardware (AEH) and COTS components in AEH (hereafter both are referred to as COTS AEH) are an inescapable necessity for aerospace vehicle development, but the rapid technological advance of COTS AEH products that are not designed for long-life, life-critical, stringent-environment applications (e.g., avionics) results in ever-growing problems and interacting issues. The COTS AEH Assurance Methods Project (AFE 75) identifies 22 current issues related to the use of COTS AEH in aircraft design, and describes each issue and their related risks and impacts. These COTS issues are already being experienced in aircraft development. They are yesterday's issues and the required standards, guidance, tools, and mitigation techniques are already late. Immediate action and rapid development are required.

The COTS (AEH) Assurance Methods cooperative research project was performed by industry and regulatory members of the Aerospace Vehicle Systems Institute under Authority for Expenditure 75 (AFE 75).. The research addresses design, component selection, certification issues for airborne electronic hardware (AEH) that incorporates commercial-off-the-shelf (COTS) items such as hybrids, multichip modules, microprocessors, FPGAs, ASICs, and small assemblies such as printed wiring assemblies and disk drives. COTS electronics products are almost unanimously targeted for markets other than aerospace, and their designs, configuration control processes, qualification methods, and reliability assurance practices are developed and implemented without regard for the needs of aerospace users. In this report, the definition of COTSstated in ANSI / EIA-933.

1.1 Principles

1) This AFE 75 COTS AEH Issues and Emerging Solutions Final Report are based on the following principles: Solutions or guidance that are too limited or rigid may be too prescriptive or specific and reduce their ability to meet application needs.
2) Solutions or guidance that are too general may fail to provide usable solutions or provide limited solutions that require significant research and development.
3) If solutions to issues already exist, find them, determine if they are available to this project, and start development of the issue solution and guidance from known possibilities
4) If solutions are unknown, hypothesize possible solutions based on our knowledge of the issues. Research available information, technologies, processes, methods, and tools to formulate potential solutions.
5) Establish a draft COTS AEH Assurance Framework for the continued research of these issues and development of issue solutions and guidance.
6) Select solutions to be worked in the AFE 75 project based on the available project resources, the feasibility of the candidate solutions, and the criticality of potential impact of the issues.
7) Identify required research and development (R&D) to establish solutions and guidance for potentially solvable issues.

1.2 Scope

The issues identified in this report are seen as a baseline set of issues given the dynamic nature of AEH technology. They may be modified as needed and additional issues may be considered if there is a compelling need to do so. AFE 75 defines how the issues can impact safety and airworthiness of aircraft, and how they can be addressed in the certification process. To the extent possible, existing industry handbooks, standards, reports, and technical publications are leveraged in a recommended document structure, and are suitable to be applied to future work beyond the scope of AFE 75. Wherever possible, as additional knowledge is required, research to produce that knowledge is described.

This research recommends:

1. how existing guidance and standards should be applied to these issues;
2. additions to existing documentation and additional documents needed for the certification process, including how those documents should fit within the certification document structure,
3. guidance providing more technical information about the issues;
4. research required to provide new knowledge needed to develop and document development and certification methods for any given issue;
5. tools to be developed and/or used in the development, certification, and maintenance processes; and
6. certification and assessment criteria and methods for the selected issues.

The scope of AFE 75 is limited to recommendations in the above areas, and it does not include fulfillment of the recommendations.

1.3 AFE 75 Project Structure

The COTS (AEH) Assurance Methods project was organized into four tasks with corresponding deliverables. Task 1 concerned the identification of issues arising from the use of COTS equipment in aerospace, defense, and other high-performance (ADHP) applications and reaching consensus on the nature and urgency of the risks associated with these issues. Task 2 involved the development of detailed descriptions of a subset of selected issues in the standardized format described in Section 2 of this report. Task 3 developed recommendations for potential solutions intended to mitigate the risks associated with selected issues. Additionally, a candidate document structure was developed (see Appendix B) to contain existing and yet to be developed guidance for the use of COTS in ADHP applications. Finally, Task 4 addressed the need for continued development by outlining suggestions for future work needed to implement the potential solutions.

1.4 Document Structure

This report is organized into three major Sections and supplemental Appendices.

Section 1: introduces the AFE 75 Aerospace Vehicle System Institute (AVSI) project, identifies the project objective, principles, structure, issue set, and document structure.

Section 2: lists the candidate issues and specifies the issues selected for AFE 75 research, describes each issue and defines the relationship to safety and certification, existing activities, technology and process weaknesses and deficiencies, recommendations and desired outcomes, and includes a separate reference and acronym list enabling each issue section to be a stand-alone segment.

Section 3: defines how AFE 75 results and conclusions are embedded in the document structure. This report is structured to provide parallel results and conclusions to allow this single document to provide documentation for each Issue.

Appendix A: provides the combined references from the entire report designed in a manner that provides a synchronized view of how the 22 issues relate to each other and to existing references and guidance documents.

Appendix B: Candidate Comprehensive Guidance Document Structure addresses a five step evolution of Candidate Comprehensive Guidance Documents to project implementation of standards and guidance documents required to address the COTS issues to the level of accomplished AFE 75 research.

Appendix C: Issue Spreadsheet provides a comparative summary of the issue set in a matrix of the following aspects of issues allowing detailed comparison of the issues:

- Identifies selected issues (Columns in the matrix and Rows for each of the following aspects):
- References relevant sections in Section 2.n.
- Identifies Current Standards.
- Does the Standard adequately address the issue defined?
- Should a new Standard be created?
- Identifies Standard owners.
- What additional work is needed for Regulatory use?
- Wherever possible, summarizes what additional research is needed.

Appendix D: Categorizes similarities in AEH COTS issues which may support planning for additional research.

1.5 COTS AEH Assurance Objective

The COTS electronics products industry is characterized by relentless pressure to expand and improve functions, reduce costs, and reduce design and development time. These concerns are accelerating rather than abating. Since aerospace is a small part of this market, it is driven by forces that are beyond aerospace control, and are often counter to the best interests of aerospace

users of COTS products. Due to the dynamic nature of the COTS industry, the issues that impact aerospace continually change, and any attempt to capture them must be viewed as a snapshot at any given time. Furthermore, the issues are interrelated and difficult to organize. Nevertheless, the issues described here represent the best good faith efforts of aerospace technical personnel with knowledge and experience in dealing with them.

AFE 75 has developed a consensus set of issues that exist at the time of this research project and attempts to identify the needs and approaches to assure safety and airworthiness of aircraft, and how they can be addressed in the certification process.

1.6 COTS AEH Issues

This research established 26 categories of candidate issues and selected 22 issues to be researched in AFE 75. Some candidate issues did not meet the AFE 75 criteria for COTS issues, one (Intellectual Property) was beyond the resources available in the AFE 75 project. Each selected COTS issue was evaluated to determine its technical characteristics and its impact on aerospace design, component selection, implementation, validation, certification and life cycle maintenance. Special attention was given to the need for awareness of these issues by both industry and regulatory agencies to attain a "level playing field" based on common agreement to the required quality of systems and aircraft and mitigation of the issue characteristics.

Table 1 identifies the Issues and Non-Issues which are identified and addressed in this report: The Multiple, Global Electronic Supply Chains (2.12) was determined not to be a technological issue, and was therefore not included in Appendix C, but remains in Section 2 for completeness.

Table 1. AFE 75 Candidate and Selected Issues

Section	Issue	Issue/Non-Issue
2.1	COTS Assemblies	Issue
2.2	Derating	Issue
2.3	Sparing Reliability	Issue
2.4	Commodity Memory	Issue
2.5	Increased Susceptibility to Atmospheric Radiation	Issue
2.6	Limited Life Semiconductors	Issue
2.7	Outdated Reliability Assessment Methods	Issue
2.8	Transition to Lead-free Electronics	Issue
2.9	Availability and Updates of Errata	Issue

2.10	Counterfeit Electronic Parts	Issue
2.11	Undocumented Features	Issue
2.12	Multiple, Global Electronic Supply Chains	Non-Technological Issue
2.13	Usage Domain Analysis	Issue
2.14	Production Follow-Up	Issue
2.15	Intellectual Property (IP)	Issue
2.16	Unknown Changes	Issue
2.17	Embedded Controllers	Issue
2.18	Technology and Component Maturity	Non-Issue
2.19	Component Packaging & Mounting Reliability	Issue
2.20	Device Uprating	Issue
2.21	Additional Handbook Considerations	Issue
2.22	Obsolescence Management	Issue
2.23	Acceptable Level of Compliance Evidence	Non-Issue
2.24	Multiple Supply Chains	See 2.12
2.25	Demonstration Methods for Safe Use of Complex COTS in AEH	Non-Issue
2.26	System On Chip Devices	Issue

2. Issue Definitions, and Recommendations

This report provides a COTS AEH Assurance Framework including a common structured approach for Industry use to evaluate COTS AEH issues. It is applied to the 22 issues and is recommended for application to future issues to support development of COTS AEH mitigations on a Project level that can be rolled into development design assurance and practical aircraft certification compliance solutions to FAA Engineers, delegates, and Standards administrators.

Each Section 2 issue is structured to include:

2.n.1 Description of the issue
2.n.2 Relationship to safety and certification
2.n.3 Existing Activity
2.n.4 Technology Weakness/deficiency
2.n.5 Process Weakness/deficiency
2.n.6 Recommendation / desired outcome
2.n.7 References
2.n.8 Acronyms and Abbreviations.

This structured approach can be used to evaluate and work emerging COTS AEH issues. The subsections below are intended to be stand-alone resources for further work on each issue. Each issue subsection contains a complete set of acronym definitions and references for this purpose. Reference numbering is self-consistent within each subsection. A full, cross-referenced list of references is provided in Appendix A.

2.1 COTS Assemblies

For purposes of this project, Commercial-off-the-Shelf (COTS) assemblies are viewed as small electronic assemblies such as printed wiring assemblies, relays, disk drives, liquid crystal display (LCD) matrices, etc. Depending on the item, the aerospace user of the assembly may have varying levels of control, but never complete control, of the design, configuration control, and qualification of the COTS assembly; thus a wide range of assurance methods may be used. This implies a wide range of costs, and there is a need for guidance for certification of systems that contain COTS assemblies. TechAmerica issued a COTS assembly management document (ANSI/EIA-933) [1] that may serve as a basis for that guidance. (Recently, ownership of this and other aerospace documents has been transferred to the SAE,, International (formerly the Society of Automotive Engineer; thus, SAE, International is used to designate such documents in this clause.)

2.1.1 Description of the Issue

Although there is no generally-agreed upon definition of a COTS assembly, the definition found in ANSI/EIA-933 is used here: *"An assembly developed by a supplier for multiple customers, whose design and configuration is controlled by the supplier's or an industry specification."*

There are many ways to categorize COTS assemblies, but for purposes of this report, that categorization is best viewed as a spectrum.

- At one end of the spectrum are COTS assemblies whose design, internal parts, materials, configuration control, and qualification methods are at least partially or indirectly controllable, by aerospace customers (either individually or collectively). An example at this end of the spectrum is a virtual machine environment (VME) circuit card assembly. While the design, internal parts, materials, configuration control, and qualification methods are controlled by the assembly manufacturers, the assemblies are targeted for aerospace applications, and thus the manufacturers expend considerable effort to understand their customers' needs; and they design, produce, and qualify their products accordingly. VME assembly manufacturers are sensitive to feedback from their customers, and are willing to make changes in response to that feedback. The response is only general, however, and it is not likely that a specific change will be made unless the manufacturer determines it to be beneficial to the product's overall market performance.
- At the other end of the spectrum are COTS assemblies whose design, internal parts, materials, configuration control, and qualification methods are not controlled, or controllable, in any way by aerospace customers (either individually or collectively). An example here is a disk drive targeted for an industry other than aerospace. Aerospace customers are not likely to obtain any information beyond the published data sheet; furthermore, the data sheet, and other important information, may be changed without notice. Typically, it is not possible for aerospace customers to purchase these assemblies to a specific data sheet.

2.1.2 Relationship to Safety and Certification

By definition, the manufacturer or supplier of any given COTS assembly is not within the control of the aerospace user of the assembly; therefore it is the responsibility of the organization that integrates the COTS assembly into an aerospace system to assure the performance and reliability of the system.

There is a wide range of approaches to assuring the performance and reliability of COTS assemblies in airborne electronic hardware (AEH) systems. Unfortunately, and all too often, nothing is done, because the user of the COTS assembly neither controls nor understands the design, parts, or materials used in the COTS assembly. Conversely, it also is possible to conduct costly tests, analyses, and other activities to understand the design, performance, and configuration control of COTS assemblies. Clearly, there is significant potential for integrators of COTS assemblies to play on a field that is not level; and one place to level that field is in the certification process. The challenge, then, is for aerospace customers to have consensus on requirements and procedures to certify that all COTS assemblies placed into service in airborne electronics hardware will have acceptable levels of reliability and performance.

2.1.3 Existing Activity

COTS assemblies and other forms of COTS have been discussed extensively in the aerospace, defense, and high performance industries over the past two decades. A number of annual COTS-related conferences are held, and numerous books, journals, and technical papers related to COTS have been published. These activities have been largely application-specific, anecdotal and ad hoc, and there is a striking lack of consensus on any structured, systematic way to approach the challenge of COTS assemblies in AEH.

The only known published standard for COTS assembly management is ANSI/EIA-933. Its scope states, in part:

> *"The purpose of this document is to define the requirements for developing a Commercial Off The Shelf (COTS) Assembly Management Plan (CAMP) to assure customers and regulatory agencies that all of the COTS (electronic) assemblies in the equipment of the Plan owner are selected and applied in controlled processes; and that the Technical Requirements detailed in Clause 3 are accomplished. In general, the owners of a CAMP are electronics equipment and system manufacturers/integrators."*

Clause 3 of ANSI/EIA-933 includes the following requirements:

- COTS Assembly Selection
- COTS Assembly Application
- Vendor Selection
- Configuration Management and Documentation
- Life Cycle Management

Some of the requirements are applicable to the COTS assembly manufacturer, and others must be accomplished by the user.

ANSI/EIA-933 is published by SAE, and the SAE Avionics Process Management Committee (APMC) [2] is responsible to maintain the document and any revisions of it. Recently, APMC began work to revise ANSI/EIA-933.

The International Electrotechnical Commission (IEC) Technical Committee (TC) 107, Process Management for Avionics (TC 107) [3], has a COTS Assembly Management document in its current program of work, but nothing has yet been published on this topic.

2.1.4 Technology Weakness/deficiency

There is no technology weakness or deficiency associated with this issue.

2.1.5 Process Weakness/deficiency

There is no aerospace industry consensus on guidance for design or reliability assurance, or the certification process for COTS assemblies in aerospace systems.

2.1.6 Recommendations/desired outcome.

Although ANSI/EIA-933 is currently used by a variety of aerospace programs, in its current form it does not adequately address all the issues identified in AFE 75. It should be revised by determining the minimum set of requirements and procedures to certify that all COTS assemblies placed into service in airborne electronics hardware will have acceptable levels of reliability and performance and no adverse impact on safety.

The introductory sub-clause to the requirements clause in the current draft of the proposed revision to ANSI/EIA-933 states:

"*A COTS Assembly Management Plan (CAMP) compliant to this document* ***shall*** *include documented processes that are available for use to accomplish the following, for the requirements listed in this clause:*

(a) Understand the System requirements allocated to the COTS assembly;
(b) Understand the capability of the "as-received" COTS assembly, with respect to the allocated System requirements;
(c) Prepare a System risk analysis, based on a comparison of (a) and (b), above; and
(d) Document appropriate risk mitigation methods[1] available for use to assure that the COTS assembly accomplishes its allocated System requirements reliably throughout the specified system lifetime.

The requirements in this Clause can be satisfied only by the Plan owner, and cannot be flowed down to a supplier, subcontractor, or other organization that is not responsible for the integration of the COTS assembly into the System."

The proposed revision also includes a "COTS Assembly Integration Report" to be used for each instance of integrating a COTS assembly into an aerospace system. It demonstrates that all of the technical requirements of the proposed revision have been addressed and satisfied. Considerable work will be required to revise ANSI/EIA-933, and the SAE APMC has the capability to do so. The proposed new revision satisfies the concerns expressed in this clause.

IEC TC 107 also is preparing a COTS Assembly Management document. Since this document will address the same issues as does ANSI/EIA-933, IEC TC 107 and SAE APMC should be encouraged to work together on these two documents, to assure not only that their requirements are consistent (identical if possible), but that they have the same "look and feel," so that users of the two documents will use the same processes to satisfy their requirements. AFE 75 endorses the work underway in IEC TC 107 and SAE APMC as part of Task 4 to address this issue and recommend that IEC and SAE consider producing a single document to avoid the inevitable divergence of two standards over time.

AFE 75 recommends that certification authorities and avionics system customers, e.g., the Department of Defense (DoD) and platform integrators, adopt IEC TC 107 and/or SAE APMC committe standard for COTS assemblies after they are released.

2.1.7 References

1. American National Standards Institute, Energy Information Administration, ANSI/EIA-933, Standard for Preparing a COTS Assembly Management Plan," August 2001
2. SAE, International, SAE "Avionics Process Management Committee" (APMC), http://www.sae.org/works/committeeHome.do?comtID=TEASSTCAPMC, last accessed 4/12/2014
3. International Electrotechnical Commission (IEC) Technical Committee 107, TC 107, "Process Management for Avionics", http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1304, Last accessed 10/27/2103

[1] The intent of this Clause is for the Plan owner to document the risk mitigation methods available to the Plan owner; with the understanding that the risk mitigation methods actually employed on a given System depend on the application and the criticality of the System. Examples of risk mitigation methods include modification of the COTS assembly, redundancy and other System design methods, modification of the COTS assembly's local operating environment, increased maintenance, planned replacement, etc. More detail regarding these methods is included in Appendix B.

4. International Electrotechnical Commission/Technical Specification, IEC/TS 62239-1, "Process management for avionics - Management plan - Part 1: Preparation and maintenance of an electronic components management plan," edited by International Electrotechnical Commission, Edition 1.0, July 2012

2.1.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in tyhis section.

AEH	Airborne Electronic hardware
AFE	Authorization for Expenditure
ANSI	American National Standards Institute
APMC	Avionics Process Management Committee
CAMP	COTS Assembly Management Plan
COTS	Commercial-off-the-Shelf
DoD	Department of Defense
EIA	Energy Information Administration
IEC	International Electrotechnical Commission
LCD	Liquid Crystal Display
SAE	Society of Automotive Engineers
TC	Technical Committee
TS	Technical Specification
VME	Virtual Machine Environment

2.2 Derating

2.2.1 Description of the issue

Most of the definitions of derating are similar and relate to enhanced components reliability. Tarr, for instance, describes derating as "*operating a component well inside its normal operating limits, in order to reduce the rate at which the component deteriorates*" [1].

The use of commercial-off-the-shelf (COTS) components for safety-critical applications may require derating of the component. This derating serves to reduce stresses on the COTS component, which will lead to longer service life and higher assessed reliability for the host assembly.

The avionics guideline IEC/TS 62239 [2] states that if the manufacturer provides derating guidelines they shall be used. If they are not provided, the applicant shall develop and document appropriate derating criteria.

There are several concerns with derating of modern COTS components.

2.2.2 Relationship to safety and certification

Derating, from a reliability perspective, can be used to reduce the semiconductor component's scaling-related internal stress. If the internal stress decreases, the likelihood of the component time dependent wear-out and failure in long life applications also decreases. However, to arbitrarily derate COTS components by following outdated derating rules might lead to decreased lifetime and reliability, and to properly derate COTS components requires knowledge of the internal design and manufacturing process, which in numerous cases may not be available for aerospace users.

2.2.3 Existing activity

Derating of COTS components has been investigated and revealed by e.g. Forsberg and Månefjord [3]. The authors describe derating of voltage, frequency, temperature, current, noise and transients, time, and some combinations of these parameters and reveal parameter derating concerns for microcontrollers, e.g. voltage, frequency, Input/output (I/O) current etc. but also other concerns such as downbinning[2], power-aware architectures[3] and process related scaling issues.

[2] A COTS manufacturer reserves the right to fulfill orders by delivering higher frequency components substituting for the original ones that were ordered. These faster components may have higher static power dissipation and faster edge rates. Faster edge rates can impact signal timing analysis, electromagnetic interference (EMI) and decoupling capacitors considerations.

[3] Typical power-aware architectures are declocking of execution units, different power sleep modes, dynamic voltage/frequency switching or power throttling, i.e. to cool down a device by turning off/slowing down execution units when a certain die temperature is reached.

More recent work has been performed by M. White [4] who also reveals some derating concerns (e.g. dynamic random-access memories (DRAM)s, where the internal voltage used for access transistors may be derived internally and cannot be affected by the external power supply voltage).

2.2.4 Technology weakness/deficiency

A typical wear-out mechanism in semiconductors is electromigration (the transport of material caused by the gradual movement of the ions in a conductor due to the momentum transfer between conducting electrons and diffusing metal atoms). By derating the frequency of a highly integrated circuit (IC) such as a microprocessor or digital signal processor (DSP) (running it at lower speeds at a given temperature) the power consumption will decrease which in turn reduces electromigration; Reference "Reliability implications of derating high-complexity microcircuits" [5].

Thus it makes sense to derate frequency of such components. However, some manufacturers may have used power reduction techniques such as advanced cutoff techniques making the effect of frequency derating non-trivial, both concerning performance and wear-out.

In addition, in many COTS components there are different frequencies on different parts on the chip which present problems as to what frequency to derate. There might also be relationships between different frequency regions which need to be maintained. Internal frequencies might also be tightly coupled to memory and I/O bus speeds. Therefore, it is very important to fully understand all frequency regions and their relationships to each other or other external environments before applying frequency derating of such components; Reference Derating Concerns for Microprocessors Used in Safety-Critical Applications.

2.2.5 Process weakness/deficiency

Several derating guidelines exist but many of them are outdated. Also, when it comes to on-chip designs, where the knowledge of the internal design plays a big role, not much derating guidance exists. However, two standards IEC/TS 62239-1 and ANSI/EIA-STD-4899-A-2009 [6] require the applicant to follow the component manufacturer's derating criteria and methods if existent. The assumption behind this is that the manufacturer knows their internal design and manufacturing process best and therefore develops most accurate derating guidance based on this knowledge. On the other hand, developers of today's components may not be the same as the manufacturer of the components which may not be the same as the ones producing the wafers with the integrated circuits and thus control the manufacturing process. Developers may also use purchased intellectual property functionality from other companies and thus having less control over the internal design. In addition, the avionics applicant may also have other conditions not typically valid for the mainstream users of the component which make the manufacturer's derating criteria difficult to use. In the end however, it is most likely that the manufacturer has better control over the internal design and manufacturing process than the applicant.

Other guidance addresses particular derating topics, e.g. IEC/TS 62396-1 [7] which addresses single-event burnouts for high voltage components and recommends voltage derating more than 50% for power components operated at > 300 volts (V).

From the military side, standards and handbooks give some derating guidance too, e.g.:

- The Military Standard, MIL-STD-1547B [8] requires a specific derating to be performed, solely based on temperature, for space and launch vehicles.
- The Military Handbook, MIL-HDBK-454B [9] states that the parts and materials selected should be used within their electrical ratings and environmental capabilities. Derating should then be accomplished as necessary to ensure the required equipment reliability within the specified operating conditions. However, to do so requires knowledge of mapping derating parameters to reliability. In addition, how do we connect derating with design assurance?
- The MIL-HDBK-338B [10] gives guidance on the specific parameters to be derated for each type of component. This handbook has however not been updated for several years which affects its usefulness for new types of components.

2.2.6 Recommendation/desired outcome

It should be clear that the issue described in this section does not apply to components where no derating is performed. The issue appears only when derating is applied. It should also be noted that derating is not mandatory for certification.

If derating shall be applied there are only two appropriate standards for avionics system applications; they are: IEC/TS 62239-1 or ANSI/EIA-STD-4899-A-2009. Their recommendations for derating are:

- When the component manufacturer provides derating criteria and methods, they shall be used.
- If the component manufacturer does not provide this information then the applicant shall develop and document appropriate[4] derating criteria and methods.
- All instances in which a component is not used within the operating limits specified by the component manufacturer (uprating) shall be documented in the design records. In all such instances, either corrective action shall be taken, or justification for not satisfying the criteria shall be documented. See also the specific topic Device Uprating (Section 2.20) in this document.

By enforcing the use of the component manufacturer's derating criteria and methods, the likelihood for unsuccessful derating of a component will likely decrease.

If the component manufacturer does not provide derating criteria, both IEC/TS 62239-1 and ANSI/EIA-STD-4899-A-2009 recommend using derating methods described in JEP149 [11] for avionics applications.

To be able to use JEP149, internal parameters and technical data used for component thermal modeling should be documented with the component manufacturer data. Also, for some processes to be performed information from the component manufacturer not provided in published data sheets may be required. In these cases, the manufacturer shall be contacted to

[4] The author is not aware of any criteria or standard defining what appropriate derating criteria and methods are, thus, it is likely that the applicant needs to define and argue for what are appropriate means in this context and coordinate this with the certification authorities to assure its appropriateness for aircraft certification.

determine the data needed to support appropriate application of the part with regard to these issues.

Because IEC/TS 62239-1 and ANSI/EIA-STD-4899-A-2009 reference JEP 149 these standards should be applied with caution when JEP149 is used for extending the service life of the component since detailed component information is needed. Without detailed information of the component, it is not practical to apply JEP149. JEP149 (with assumptions[5]) may however be applied as the model and process when derating is used for design margins and not for increasing the service life.

It is recommended that when IEC/TS 62239-1 or ANSI/EIA-STD-4899-A-2009 is subject for other updates, these standards' derating sections should be updated with a caution note regarding the use of JEP149 for extending the service life of the component since detailed component information is needed, to include guidance concerning how JEP149 may be applied when derating is used for design margins, see above. IEC/TS 62239-1 or ANSI/EIA-STD-4899-A-2009 should be used as soon as possible as guidance document if derating is performed. The issue appears only when derating is applied. It should also be noted that derating is not mandatory for certification.

AFE 75 has no further recommendations.

2.2.7 References

1. Tarr, M., "Derating," Online postgraduate courses for the electronics industry - Topics Library, Reliability issues and failure mechanisms, The University of Bolton, available at http://www.ami.ac.uk/courses/topics/0190_drat/index.html
2. International Electrotechnical Commission/Technical Specification, IEC/TS 62239-1, "Process management for avionics - Management plan - Part 1: Preparation and maintenance of an electronic components management plan," edited by International Electrotechnical Commission, Edition 1.0, July 2012.
3. Forsberg, H. and Månefjord, T., "Derating Concerns for Microprocessors Used in Safety-Critical Applications," IEEE Aerospace and Electronic Systems Magazine, March, 2009.
4. White, M., "Scaled CMOS reliability and considerations for spacecraft systems: Bottom-up and Top-down Perspectives," Reliability Physics Symposium (IRPS), 2012 IEEE International, Anaheim, CA, USA, April 15-19, 2012.
5. Biddle, S. R., "Reliability implications of derating high-complexity microcircuits," *COTS Journal*, Vol. 2, No. 2 February 2001.
6. TechAmerica Standard, ANSI/EIA-STD-4899A-2009, "Standard for preparing an electronic components management plan," February 11, 2009.
7. International Electrotechnical Commission/Technical Specification, IEC/TS 62396-1, "Process Management for Avionics – Atmospheric Radiation Effects – Part 1: Accommodation of Atmospheric Radiation Effects within Avionics Electronic Equipment, Edition 1.0, March 2006.

[5] These assumptions may be explained to the certification authorities before use.

8. Military Standard, MIL-STD 1547B, “Electronic parts, materials, and processes for space and launch vehicles,” 1 December, 1992.
9. Military Handbook, MIL-HDBK-454B, “General guidelines for electronic equipment,” 15 APRIL 2007.
10. Military Handbook, MIL-HDBK 338 B, “Electronic reliability design handbook,” 1st of October 1998.
11. Joint Electronic Device(s) Engineering Council (JEDEC), Solid State Technology Association, JEP149, "Application thermal derating methodologies," November 2004.

2.2.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section.

ANSI	American National Standards Institute
CA	California
CMOS	Complementary-Metal-Oxide-Semiconductor
COTS	Commercial-off-the-Shelf
DRAM	Dynamic Random-Access Memory
DSP	Digital Signal Processor
EIA	Energy Information Administration
EMI	Electromagnetic Interference
HDBK	Handbook
IC	Integrated Circuit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
I/O	Input/output
IEC	International Electrotechnical Commission
IRPS	International Reliability Physics Symposium
JEDEC	Joint Electronic Device Engineering Council
JEP	JEDEC Publication
MIC	Many Independent Core
MIL	Military
STD	Standard
TS	Technical Specification

USA	United States of America
V	Volts

2.3 Sparing Reliability

2.3.1 Description of the issue

As feature sizes decrease and processes and materials change continuously, the potential for on-chip defects increases. Device manufacturer can counter this with “sparings”, i.e. on-chip redundancy to improve wafer yield.

Sparings can also be used for lifetime reliability enhancement, where spare structures are turned on when the original structures fail.

On-chip redundancy to improve wafer yield, has been used by the manufacturer of Commercial-off-the-Shelf (COTS) electronics product items aimed for the consumer market for a long time. Intel presented ideas for improving wafer yield using on-chip redundancy for static random access memory (SRAM) memories already in 1997 [1].

A well-known example of sparings is Sony’s PlayStation 3. The PlayStation 3 uses the Sony, Toshiba, International Business Machines (IBM)-designed Cell microprocessor as its central processing unit (CPU), which is made up of one PowerPC-based power processing element and eight synergistic processing elements (SPEs). To increase fabrication yields, Sony ships PlayStation 3 Cell processors with only seven working SPEs [2].

Another recent multicore device, Intel’s Knight’s Corner (KNC), also uses on-chip redundancy to improve wafer yield. But in this case, the number of usable cores also depends on other factors such as clock speed. T. P. Morgan [3] writes “*Intel has been cagey in public talking about how many cores are physically on the Knights Corner coprocessor, and has only committed to saying that it is going to be larger than 50. The real answer is that there are 64 cores on the die, and depending on yields and the clock speeds that Intel can push on the chip, it will activate somewhere between 50 and 64 of those cores and run them at 1.2 GigaHertz (GHz) to 1.6 GHz*”.

2.3.2 Relationship to safety and certification

It is known that at least one embedded microcontroller suitable for the avionics industry is sold as a single core but is in fact a defective dual core. The manufacturer has revealed that both cores must be powered even though only one should be used. To avoid accidental execution of the incorrect working core, a “core disable” pin must be set to ground. Execution of “unknown cores”, defective or not, may affect shared resources such as common cache memories etc. such that the expected working core experience unwanted undeterministic behavior.

Another concern is the other way around, i.e. if one core is only slightly defective, this microcontroller may be potentially remarked and sold as a working dual core. For the avionics industry, where frequency derating is more common than other industries, both cores may work well at the derated frequency but the margins to failure are much closer than was originally calculated.

Furthermore, researches have proposed ideas to use redundancy at finer granularities in order to achieve more efficient use of redundant hardware. The extent of that concern for the certification process is not fully understood.

2.3.3 Existing activity

Srinivasan, Jayanth *et al.* [4] have studied two techniques of sparings that leverage microarchitectural structural redundancy for lifetime reliability enhancement. The first technique, structural duplication, uses redundant microarchitectural structures in the processor which are designated as spares. Spare structures can be turned on when the original structure fails (in extreme cases already at shipment to counteract on-chip defects during manufacturing), increasing the processor's lifetime without loss of performance but to the cost of increased die size. The suggested solution relies on power gated spare structures thus it is not expected that the effect of single-event upsets will change during the lifetime of the device. Using this technique however leads to another challenge and that is the assured shutting down of the failed structure. The technique should ensure that shut down units do not become active again, or that units cannot be shut down by false failure indications and possible cascading down.

The other described technique is called graceful performance degradation (GPD). It is a technique that exploits existing microarchitectural redundancy for reliability. Redundant structures that fail are shut down while still maintaining functionality but at a lower performance. As long as the manufacturer reveals the eventual performance loss due to this technique, it still may be possible to maintain a controlled behavior. It may however be harder to evidence and create safety-nets for them.

Abhisek Pan *et al.* [5] have proposed a similar technique as the GPD but on a coarser granularity. Their approach improves reliability on chip multiprocessors and at the same time improves the yield but at the cost of some performance loss. They exploit the natural redundancy that already exists in multi-core systems by using services from other cores for functional units that are defective in a faulty core. To make it work they use a micro-architectural modification that allows a core on a chip multiprocessor to use another core as a coprocessor to service any instruction that the former cannot execute correctly.

Through simulation of a dual-core system with one or two cores sustaining partial failure, Abhisek Pan *et al.* have shown that large and sparingly-used units such as floating point arithmetic units can run each faulty core with help from companion cores with low impact to performance and very little area overhead. Their simulation shows that significant yield recovery is possible with only 10-15% performance degradation in the worst case. However, through normal maintenance activities the margin of performance available may become small enough to allow even low impact to cause degraded performance. In addition, to predict worst case execution times on these types of devices, the manufacturer has to provide built-in test features, where it is possible to simulate all kinds of faults that can be mitigated through "delayed" and shared (during faults) services from other cores. Still, it might be hard to understand the non-deterministic behavior in real applications with multicore processors that implements this micro-architectural modification.

Another example of sparings is utilized in some IBM Power 7 servers. These servers provide a "self-healing capability" in memory, automatically moving data from failed Dynamic Random Access Memory (DRAM) chips to available spares [6].

2.3.4 Technology weakness/deficiency

Using redundancy to improve yield will become more and more evident the smaller the geometries will be used by the manufacturer due to several reasons, e.g. higher transistor count, increased clock frequencies, reduced effectiveness of accelerated life tests (burn-ins), and new aging defect mechanisms such as negative bias temperature instability (NBTI), positive bias temperature instability (PBTI) and time dependent dielectric breakdown (TDDB) [5].

One could argue that devices with redundancies be considered as part of the failsafe or operational safety net requiring additional capacity to counteract loss of performance due to repetitive failure. However, research [7] has shown a clear relationship between failure rates and technology scaling. This indicates that microarchitectural redundancy should preferably be seen as an enabler for using smaller geometry devices rather than as a part of an operational safety net (unless it is purposely used for fault-tolerance purposes such as IBM's Power6 microprocessor [8]).

2.3.5 Process weakness/deficiency

The authors are not aware of any process guidance for safety-critical systems dealing with devices utilizing yield improvement technologies. It seems as if failures will occur in development and operation changing the risks and characteristics of the devices. Should requirements for continuing evaluations in the operational environment be developed and required? Should devices containing such redundant architecture be used in avionics systems? What requirements are required to reduce operational risks?

2.3.6 Recommendation/desired outcome

AFE 75 believes sparings is not ready yet for regulatory use and should not be used when it may affect performance and deterministic behavior. Professional level research across the integrated circuit (IC) industry is needed to better understand the scope of this problem. The avionics industry should however be aware since in some examples it is obvious that sparings may have uncontrolled impact.

AFE 75 advises university level research to assess different types of sparings (e.g. coarse versus fine grain, with or without shared resources) and to what extent it is used by the manufacturer today and what potential impact it may have for the avionics industry. The results of the research would include the creation of processes and objectives which address this issue. In addition, AFE 75 recommends that regulatory agencies issue guidance which implements those research results. Finally, AFE 75 recommends the generation and distribution of a white paper which describes this issue, along with recommended practices and direction, for the semiconductor industry.

Sparings should preferably be divided into two problem domains; 1) when redundancy techniques are used for improving yields or extending the lifetime of the device (with or without performance degradation) and are not visible for the customer, and 2) when these techniques are used and are visible for the customer. The focus should then be on understanding the extent

where sparings are used and are not visible for the customers. If the techniques are visible, usage domain analysis may be seen as alternative guidance material, see specific topic *Usage Domain Analysis*, Section 2.13, in this document.

2.3.7 References

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8. Reick K. *et al*. "Fault-Tolerant Design of the IBM Power6 Microprocessor", IEEE Micro, March-April 2008.

2.3.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used within this section.

AFE	AVSI Authorization for Expenditure
AVSI	Aerospace Vehicles Systems Institute
COTS	Commercial-Off-The-Shelf
CPU	Central Processing Unit
DRAM	Dynamic Random Access Memory
GPD	Graceful Performance Degradation
IBM	International Business Machines
Ghz	GigaHertz
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
ISCA	International Symposium on Computer Architecture

KNC	Knight's Corner
MIC	Many Independent Core
NBTI	Negative bias temperature instability
PBTI	Positive bias temperature instability
Q4	4th Quarter
RAS	Reliability, Availability, Serviceability
SPE	Synergistic Processing Elements
SRAM	Static Random Access Memory
TDDB	Time dependent dielectric breakdown

2.4 Commodity Memory

2.4.1 Description of the issue

Modern dynamic random access memory (DRAM) and Not-AND (NAND) flash memories bring tremendous value to electronic products. Their high capacity, small packaging and modest costs make them attractive for product markets of all types, including safety-critical products such as avionics. Their use in high-volume consumer electronics market has made them commodity devices due to pricing pressures.

These devices contain billions of transistors. To achieve this level of capacity, memory suppliers use aggressive feature sizes and layout techniques, complex design approaches (e.g. Multi-Level Cell NAND), smaller design margins, and smaller noise margins [1, 2, & 3]. The need for high yield, due to commoditization, has pushed suppliers to use smaller test margins and adaptive test flows which are based on the results of recently tested die [4 & 5]. These practices reduce robustness of the devices' manufacturing tests.

These techniques and approaches make modern memory devices less reliable than earlier-generation devices. Error detection and correction circuitry is needed to make modern commodity memory devices more reliable and thus suitable for use in avionics. Development of fault distribution models which are adapted to the avionics environment (temperature, neutron single-event upset (NSEU), etc.) and avionics equipment lifetime (20 years or more) is needed so sufficient error detection and correction can be determined. These models would provide failure distributions and rates for various failure modes such as gate oxide degradation due to program/erase cycles and read disturb errors due to successive reads without intervening program/erase cycles. If provided by the device memory suppliers, the models would enable the development of more reliable avionics and allow consistent application of these devices by avionics suppliers.

2.4.2 Relationship to safety and certification

Error detection and correction methods for both DRAM (Hamming codes) and NAND flash (cyclic codes) are well known, trusted, and extensively used [6 & 7]. These methods are heavily utilized in avionics. Their effectiveness can be quantified for bit errors of any size and used in the fault trees for high integrity systems. If they are not used, DRAM and NAND flash present significant data integrity challenges for designers of avionics. If an appropriate level of error detection and correction is used, this issue is limited to one of reliability and availability (i.e. data integrity is ensured by the error detection).

2.4.3 Existing activity

Within the aerospace industry, several activities within the Aerospace Vehicle Systems Institute (AVSI) are addressing integrated circuit reliability, including AFE 17, AFE 70, AFE 71, AFE 80 and AFE 83. Many individual aerospace companies are addressing commercial-off-the-shelf (COTS) reliability, including commodity memories, see [8] for an example. In addition, the integrated circuit industry addresses integrated circuit reliability, see [9] for an example.

2.4.4 Technology weakness/deficiency

Pressure to reduce test time for DRAM has opened the possibility for devices with “weak-bits” to escape from memory manufacturers and be used in high reliability products. Reference [10] is one of few studies which attempt to gather and quantify real-world DRAM reliability results.

The very high density and relatively high voltages in NAND flash makes these devices susceptible to several “disturb” errors (“read”, “program”, and “pass” disturb errors, see [3]). These errors are “soft” in the sense that they are not destructive. Note, however, that NAND flash is a non-volatile memory. The errors remain until the block is erased and the page is re-programmed. Program/erase wearout is also a major concern for NAND flash. Error detection and correction, usually via cyclic codes, provides a safety-net for these errors. However, the amount of correction necessary is growing at a rapid pace. Without accurate fault distribution models an accurate assessment of the amount of error correction necessary for a given application is difficult to determine.

Other NAND reliability concerns include fast wear-out in cases where “wear-leveling” is not done, data retention (leakage from the floating gate), and the practice of selling NAND with defective cells (usually limited to 1% of the cells). [3&9]

Note that the use of “integrated” solutions for NAND flash (e.g. Multimedia Card (MMC) and variants) doesn’t necessarily address this issue. These solutions integrate the NAND memory, an industry-standard interface, and memory controller into one package [3]. While error detection and correction is usually included in the memory controller, the long-term reliability may or may not be properly addressed in these designs. For example, if the controller didn't account for the avionics lifetime, or expected a certain wear-leveling algorithm to be used, the reliability of these solutions may be much less than expected. In addition, third-party design of the controller may present other design assurance questions.

2.4.5 Process weakness/deficiency

There is no standardized process to obtain fault distribution models from memory suppliers. For some suppliers and devices, development of fault distribution models based on source information from the suppliers would be acceptable. These models need to be adapted to the avionics environment (temperature, NSEU, etc.) and avionics equipment lifetime (20 years or more). Other devices will require additional information and assistance from the supplier to develop models suitable for the avionics environment.

2.4.6 Recommendation/desired outcome

AFE 75 recommends that further research be performed by a university on this issue. If the university approach proves unsuccessful, collaborative research with memory manufacturers is recommended. A desired outcome is the creation of an aerospace working group which builds a framework for collaboration between commodity memory suppliers and the aerospace industry. The working group, for example JEDEC, would address the development and use of fault distribution models and the required error detection and correction for commodity memories which are suitable for avionics equipment lifetime and environment.

In addition, the commodity memory industry could benefit from additional research to further describe the problem, explain the reasons for concern, and provide recommendations to assist the aerospace community when using these memories in their products.

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2.4.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AFE 17	Methods to Account for Accelerated Semiconductor Wear Out
AFE 70	Integrated Reliability Processes
AFE 71	Reliability Prediction Software
AFE 80	Integrated Reliability
AFE 83	Semiconductor Reliability
AVSI	Aerospace Vehicle System Institute
COTS	Commercial-off-the-Shelf
DED	Double Error Detection DRAM
DRAM	Dynamic Random-Access Memory
IBM	International Business Machine
IC	Integrated Circuit

IEEE	Institute of Electrical and Electronics Engineers
MMC	MultiMedia Card (flash memory card)
NAND	Not AND, i.e. negation of Logical “AND”
NSEU	Neutron Single Event Upset
SAE	Society of Automotive Engineers
SEC	Single Error Correction

2.5 Increased Susceptibility to Atmospheric Radiation

2.5.1 Description of the Issue

Logic, memory, field-programmable gate array (FPGA), and other complementary-metal-oxide-semiconductor (CMOS) devices are susceptible to a broad class of atmospheric radiation effects called Single Event Effects (SEE) that can result in data corruption and system faults. These phenomena are the result of the interaction of high-energy cosmic rays with the earth's atmosphere, which produces high-energy neutrons that can cause SEE. SEE are more likely to occur at the altitudes in which commercial aircraft operate, than at sea level, where most commercial-off-the-shelf (COTS) electronics product items are targeted for operation. The critical charge required to cause SEE decreases as feature sizes shrink; and the likelihood of multiple-bit and multiple-cell events increases; thus the effects of atmospheric radiation on avionics systems become more troublesome.

2.5.2 Relationship to safety and certification

There always will be a need for more information, data, and understanding of the nature of atmospheric radiation and its impacts on avionics systems; however, the most immediate need is to synthesize currently-available knowledge into a set of requirements or guidelines that normalize the process for certification analysis with respect to the impact of SEE on safety. This is necessary to ensure that the proper steps are being taken to mitigate the effects of SEE, and to ensure that all providers of avionics systems are operating to the same set of rules, consistently applied.

2.5.3 Existing Activity

There is currently no consensus on how to address SEE in airborne electronic hardware (AEH) safety and certification processes. There is no consistency among various aerospace system stakeholders, e.g., platform integrators or system manufacturers, regarding how, or even whether, to require avionics system manufacturers to address the effects of atmospheric radiation in their products. The result is that the "solutions" used by the manufacturers range from completely ignoring the issue, to conducting extensive, costly, and time-consuming tests and analyses at various stages in the design, production, operation, and support of avionics systems, and at various indenture levels within the systems. The result of this situation is that system manufacturers often are not operating by the same set of rules in system development, and certification analysts do not have a consistent set of rules to use in evaluating certification applications, with respect to SEE. The result is that a wide range of certification methods (including ignoring the issue altogether) are being used inconsistently, with potentially a wide range of cost and performance on AEH.

This issue also is the focus of another Aerospace Vehicle Systems Institute (AVSI) project, AFE 72, which has issued additional technical reports [1]. AFE 72 also has recommended certification guidance for mitigating the effects of atmospheric radiation but that guidance has not yet been accepted by SAE S18/Eurocae WG-63 [2] the committees that are responsible for the development of the standards.

AFE 72 is currently contributing to the following standards

- IEC TS 62396 series [3-7]
- There is a sixth part of this series under consideration. This additional part will address the extreme space weather impact on airborne systems.
- A draft revision to ARP4761 [8], through a draft Aerospace Information Report [9] to address SEE.
- AFE 72 also plans to support updates to JEDEC Standard JESD89 [10] which are currently underway via an IEC TC47 working group.

Both the Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) have begun to take steps to require applicants to address SEE. In addition, the FAA and EASA are supporting the AFE 72 group working with WG-63 in the development of the above ARP4761 and the draft Aerospace Information Report.

RTCA DO-248C [11] also discusses SEE and mitigation techniques, but does not require any action.

2.5.4 Technology weakness/deficiency

Logic, memory, FPGA, and other CMOS devices are susceptible to a broad class of atmospheric radiation effects called SEE that can result in data corruption and system faults. These phenomena are the result of the interaction of high-energy cosmic rays with the earth's atmosphere, which produces high-energy neutrons that can cause SEE.

In the approximately 20 years since aircraft electronics were first observed to be susceptible to errors induced by neutrons generated by cosmic rays within the atmosphere, the topic of SEE has become increasingly important and difficult to manage. The issue is especially critical to aerospace electronics because the flux density of atmospheric neutrons at an altitude of 40,000 feet is approximately 300x that at sea level. As technology trends continue toward smaller feature sizes and lower voltages, CMOS devices are becoming more susceptible to atmospheric radiation effects. Government and customer specifications increasingly require assessments of the probability of SEE and their impacts to the safety and reliability of avionics systems. The actual number of these documents is growing very quickly. In addition, the level of details in the documents is also accelerating.

It is important to distinguish between the effects of atmospheric radiation and those of the radiation found in space. For electronics operating in space, the radiation of most concern is that of heavy ions and protons, and its intensity is usually described in terms of total dose. For electronics operating within the earth's atmosphere (from sea level up to about 80,000 feet), atmospheric neutrons are the dominant cause of concern. Over the past several decades, considerable effort has been exerted to address and mitigate the effects of space radiation, such as the use of radiation-hardened devices and extensive testing and selection of semiconductor devices used in space applications. Generally, the costs of the methods used to address space radiation cannot be justified for electronics operating within the earth's atmosphere.

Cosmic rays, which generate high-energy neutrons, are constantly bombarding the earth. The flux varies with global position, altitude and solar activity, but all surface locations are exposed to this radiation. At the altitudes seen by aircraft, neutrons are the main area of concern and have

been shown to be most responsible for causing SEE in aircraft electronics. Interactions of neutrons with semiconductor device active charge regions cause SEE and can take on various forms, such as upsets, functional interrupts, and latch up.

When cosmic rays penetrate the magnetic fields of the earth and reach the earth's atmosphere, they collide with atomic nuclei and create secondary radiation which leads to a high flux of energetic particles. These secondary particles include neutrons, protons and pions; with the neutron being most prevalent. Neutron energies range from 1 to 1000 million-electron-volts (MeV) and are able to interact with silicon-based technologies. Figure 1 (reproduced from [3]) shows the energy spectrum at 40,000 feet and latitude 45 degrees.

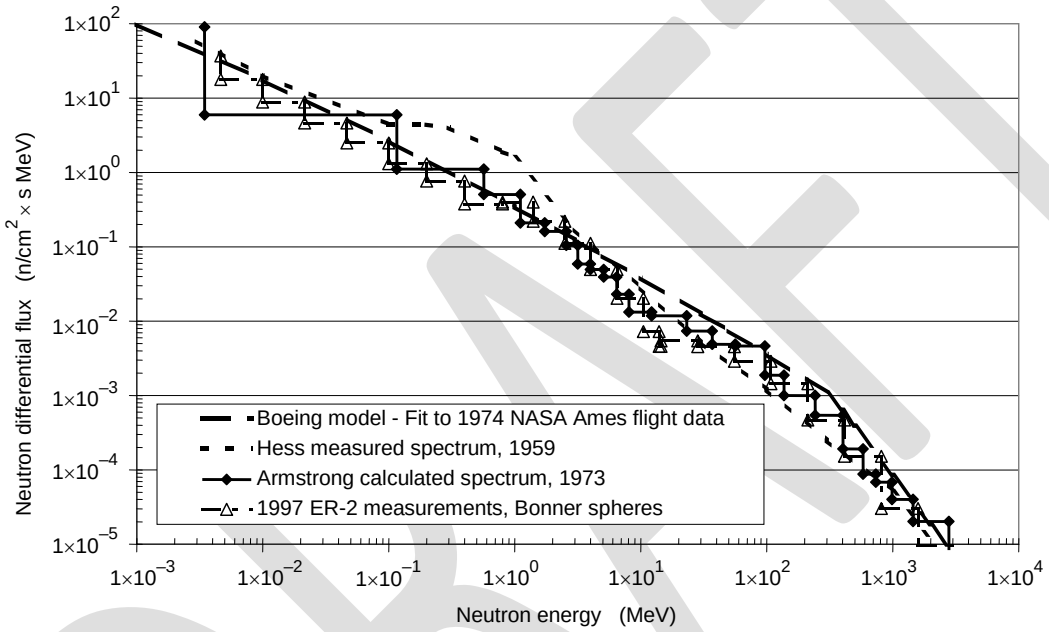

Figure 1. Energy Spectrum of atmospheric neutrons at 40,000 feet latitude 45 degrees.

The flux density of the neutrons depends on both latitude and altitude; and the largest single variant is altitude. Typical commercial airliners operate up to 40,000 feet, where the flux density is approximately 300 times greater than that at sea level. There are several reasons why the risk of SEE in avionics electronics systems is increasing.

- Technology is trending towards smaller feature sizes, higher densities, and lower voltages; resulting in greater susceptibility to atmospheric neutrons
- The numbers of memory bits and registers are greatly increasing
- The number of flights at higher altitudes is increasing due to better fuel efficiency
- The number of polar flights is increasing

SEE are a design issue for all airborne and high reliability ground-based systems. While most neutrons passing through a semiconductor device will have no impact, those that do strike silicon

atoms can flip bits. They can cause systematic functional operational errors on complex semiconductor microcircuits including devices such as memories, microprocessors and programmable devices.

SEE are caused when a radiation-generated ionization charge exceeds a device critical charge. Because secondary neutrons are uncharged they do not generate ionization directly. Rather, the neutrons collide with atoms in the electronic device, normally silicon atoms, momentum is transferred, and the recoil generates ionization. Deposited charges, through the recoils they create within a sensitive portion of a device, result in malfunction of the device. The probability for a SEE to occur at a particular energy is determined by the device cross section for that effect. SEE can cause various failure conditions, such as data corruption or even system failure. Additional types of undesirable effects include:

- damage to hardware
- corrupted logic residing in volatile memory
- corrupted data in memory
- microprocessor halts and interrupts
- writing over critical data tables
- unplanned events, including loss of mission

2.5.5 Process weakness/deficiency

The International Electrotechnical Commission (IEC) has issued a series of documents that provide extensive technical background and guidance on this issue [3-7]; however, that and other knowledge in this field have not been translated into formal guidance that is available and easy to use by device manufactures, AEH users, or regulatory agencies.

The different types of single event effects, and the associated circuit response, are defined in Table 2.5-1. When measuring a system's SEE susceptibility, the devices, the probability of exposure, and the functional unit criticality all need to be taken into account.

Table 2. SEE Types

Single Event Effect Type	Definition	Circuit Response
Single Event Upset (SEU)	in a semiconductor device when the radiation absorbed by the device is sufficient to change a cell's logic state Note: After a new write cycle, the original state can be recovered.	A change of state in a memory or latch in a device induced by the energy deposited by an energetic particle.
Multiple Bit Upset	the energy deposited in the silicon of an	Occurs when the energy deposited in

Single Event Effect Type	Definition	Circuit Response
(MBU)	electronic device by a single ionising particle causes upset to more than one bit in the same word	the silicon of an electronic device by a single ionising particle causes upset to more than one bit in the same logical word.
Multiple Cell Upset (MCU)	the energy deposited in the silicon of an electronic device by a single ionising particle induces several bits in an integrated circuit (IC) to upset at one time	Occurs when the energy deposited in the silicon of an electronic device by a single ionising particle induces bit upsets in more than one physically adjacent bit in an integrated circuit (IC).
Single Event Latchup (SEL)	in a four layer semiconductor device when the radiation absorbed by the device is sufficient to cause a node within the powered semiconductor device to be held in a fixed state whatever input is applied until the device is de-powered, such latch up may be destructive or non-destructive	A condition that causes the loss of gate or device function or control due to a single event induced high current state. May or may not cause permanent failure, but requires power cycling to return IC to normal operations if undamaged. Latchup can cause circuit lockup and/or device failure.
Single Event Transient (SET)	spurious signal or voltage, induced by the deposition of charge by a single particle that can propagate through the circuit path during one clock cycle	A spurious signal or voltage propagating through a circuit path during a single clock cycle. Note: for frequency above 100 MHz the potential for SET in digital devices increases. Produces transients which may affect subsequent circuits if not well filtered in design
Single Event Functional Interrupt (SEFI)	occurrence of an upset, usually in a complex device (e.g. a microprocessor), such that a control path is corrupted, leading the part to cease to function properly Note: This effect has sometimes been referred to as lockup, indicating that sometimes the part can be put into a "frozen" state	An SEU in a complex device such that a control path is corrupted, leading the IC to cease to function properly. Often induced from SEU in control registers of a complex device and recovered by reset or power cycle.
Single Event Gate Rupture (SEGR)	in the gate of a powered insulated gate device when the radiation charge absorbed by the device is sufficient to cause gate rupture, which is destructive	An SEGR is manifested by an increase in gate leakage current and can result in either the degradation or the complete failure of the device.
Single Event Burnout (SEB)	burn out of a powered electronic device or part thereof as a result of the energy absorption triggered by an individual radiation event	A condition which can cause device destruction due to a high current state in a power semiconductor device.

Acknowledgement these definitions are taken from IEC62396-1

Not every SEE will result in a system fault, e.g., if a fault occurs in an unused part of the system, and there is no physical destruction, there is no effect. Those faults that do propagate through the system result in either a detected or undetected error. Faults which can occur include:

- Hard error – not recoverable by software reset and requires removal of power to recover normal operation; non-recoverable example is an integrating system that cannot withstand removal of power and still recover during a flight.
- Hard failure – results in loss of function in the device and the need for device repair. An example of a hard failure in a memory cell is a gate or dielectric rupture, or latch-up which permanently damages the device.
- Soft error – nondestructive and recoverable; generally affects storage elements, such as memory, latches and registers. Worst case effect results in hazardous misleading information.

The SEE response of CMOS devices is complicated and has been shown to increase significantly with advancing integrated circuit technologies, e.g., reduced feature size. Current data indicates that the MBU rate rises significantly for feature sizes <90 nm. In a similar manner different revisions of the same device (identical part number) incorporating modifications in their die fabrication process, can dramatically change from no sensitivity to a pronounced SEE sensitivity.

As feature sizes become smaller, the ranges of the spectrum that can cause SEE increases, as shown in Figure 2. The range extends into lower energies, where the flux densities are higher.

Note: There is an additional SEU rate in some devices contributed by the low energy neutrons (called thermal neutrons) that exist within aircraft. While the high energy neutrons cause SEUs through interaction with the Silicon (Si) atoms, thermal neutrons cause SEUs through their interaction with Boron-10 that is found in some microelectronics. This is further discussed in section 5.6 of IEC/TS 62396-1 and also in IEC/TS 62396-5. Where possible, parts containing boron 10 or natural boron should be avoided. When assessing SEE rates, thermal neutron effects should be considered when appropriate.

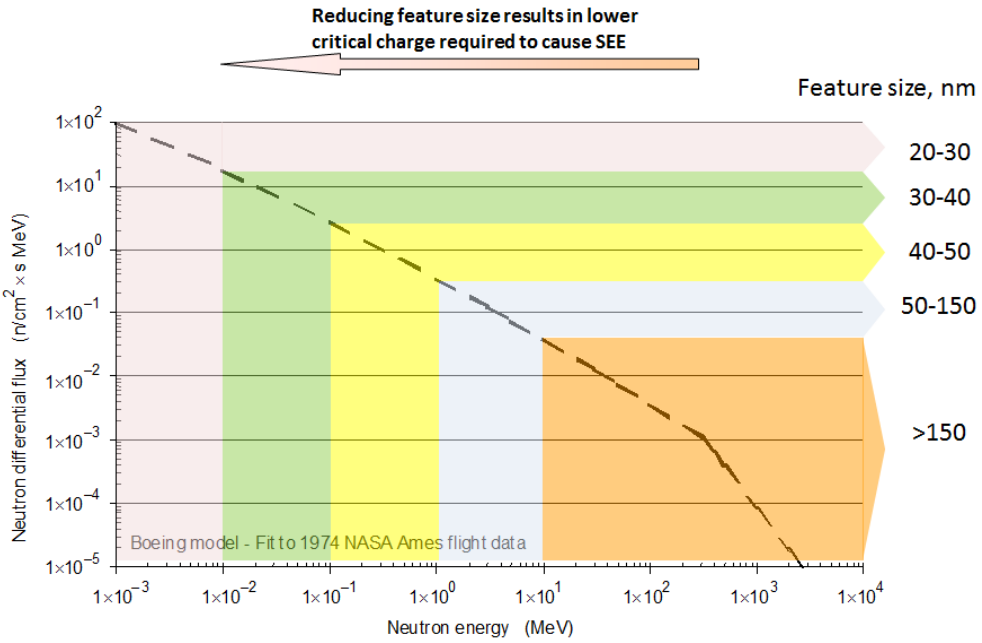

Figure 2 As feature sizes become smaller, a larger range of atmospheric neutrons energies can cause SEE.

Aerospace industry specifications and standards currently exist to provide avionics system designers with background information on the atmospheric radiation environment, general information on SEE, and testing methods. Most notably for the avionics industry is the IEC TS/62396 series of documents [3-7], published by International Electrotechnical Commission Technical Committee 107, Process Management for Avionics (IEC TC 107) [12]. These documents inform avionics systems designers, manufacturers, and their customers of the kind of ionising radiation environment that their semiconductor devices are subjected to in aircraft, the potential effects this radiation environment can have on those devices, and some general approaches for dealing with these effects.

2.5.6 Recommendation/desired outcome

The need for access to timely data and information for use in SEE analysis is critical. The two potential sources of such information are (1) a test facility that is capable for avionics applications, and (2) data that is currently in the possession of CMOS device manufacturers.

To address the former, it is recommended that the aerospace industry cooperate with AVSI project 72, Oak Ridge National Laboratory (ORNL) [13], and other concerned parties to pursue the development of SEE test capability at ORNL.

To address the latter, AVSI Project 75 recommends the formation of an aerospace industry organization to communicate, on an industry-to-industry basis, with the semiconductor device

industry to assure the timely availability of data necessary to perform SEE analysis. Discussions of this nature already are occurring at the technical level through organizations like the Joint Electronic Device(s) Engineering Council (JEDEC) [14], but there is a need to communicate at higher management levels, and to institutionalize the agreements made from these communications. (This approach also may be used to address other issues raised by this project, such as the life-limited-semiconductor issue, addressed in Section 2.6 of this document.)

There is no single, simple solution to the complex issue of SEE due to atmospheric radiation in avionics systems. Furthermore, the SEE problem that needs to be solved will continue to morph and change as CMOS technology continues its relentless progression. Therefore, the "solutions" discussed here should be considered as areas in which aerospace users of semiconductor devices should be concentrating their efforts to address SEE. Generally, the following areas should be considered:

1. Obtaining data and other information required for effective analysis at the device, assembly, system, or platform level;
2. Conducting analyses at the above levels to evaluate the impact of SEE; and
3. Implementing design, production, operating, or maintenance practices that reduce or mitigate the effects of SEE.

Finally, information from the above areas must be synthesized into a comprehensive, but brief, set of requirements and guidelines that can be used for design, production, operation, support, and certification of avionics systems with respect to SEE. The guidelines must be understood, and used effectively and consistently by all stakeholders.

Each of the three areas listed above is discussed briefly here.

1. Obtaining data and information. The most obvious way to obtain data is by testing the device prior to use. Guidance for testing for SEE susceptibility is provided in [3]. Although the test itself is neither difficult nor expensive, it is complicated by the need for proper analysis equipment, and also by the limited availability of test facilities that have the proper neutron spectrum. It is possible to test one device that is representative of a family of similar devices from the same manufacturer; but this must be done with caution. Many CMOS device manufacturers have information that is not published on their data sheets that could be useful in SEE analysis; however, the process for obtaining it is not well-defined. Many manufacturers would be willing to make the information available on an industry-to-industry basis, but not company-to-company. In 2010, AVSI project 72 worked with ORNL [13] to develop a proposal for a Cosmic Ray Neutron Simulation Facility at ORNL that would provide SEE testing capability for aerospace and other high performance systems, at an estimated cost of $44M. The FAA is continuing to work with ORNL to better understand and define what the desired capabilities can and should be for such a facility. It is recommended that AFE 75 work with AFE 72 for further research input to support this capability.
2. Conducting analyses. A SEE analysis plan should be done for all new product developments, system upgrades, or parts replacements due to obsolescence or other design changes. The analysis begins with the assessment and classification of all devices included in the Bill of Materials. A review of the information results in either the need for an evaluation or a determination that the assessment is acceptable and can be directly incorporated into a safety assessment. If an evaluation is required, each susceptible part is analyzed, and existing device and system mitigations are taken into account. If required, SEE susceptibility tests are

conducted. The data are analyzed, cross-sections of the susceptible devices are determined, and an impact analysis on system operation is performed. With this information, the need for and degree of mitigation can be determined. When the evaluation is complete, SEE faults and system effects are summarized. ARP4761 [8] and the draft Aerospace Information Report [9] provide more detailed information on the SEE analysis process. It is recommended that AFE 75 work with AFE 72 to prepare a White Paper containing (a) a list of required and/or recommended documents to define the SEE analysis process; and (b) requests to the organizations that should develop and maintain the documents.

3. Implementing solutions. Solutions may be implemented at various indenture levels in the system design, and at various stages in the design, production, and use cycle. It is recommended that AFE 75 work with AFE 72 to (a) prepare a list of implementation documents to be used by AEH customers and regulatory agencies; and (b) requests to the organizations that should develop and maintain the documents.

IEC TS 62239-1 [15], contains the following requirement to address the effects of atmospheric radiation (reproduced from IEC TS 62239):

"4.3.7 Avionics radiation environment

The documented processes shall verify that the components will operate successfully in the application with regard to the effects of atmospheric radiation on them. These include various types of single event effects (SEE), such as single event upset (SEU), single event latch-up (SEL), single event burn-out (SEB) and single event functional interrupt (SEFI). If radiation effects are accommodated by the equipment design, then the method of accommodation shall be documented in the equipment design records. Guidance on the effects of atmospheric radiation may be found in the IEC 62396 series [3-7]. The effects of atmospheric radiation and their accommodation shall be assessed and documented in accordance with the SEE compliance Clause 9 of IEC 62396-1:2012 and with reference to the other parts of the IEC 62396 series.

The SEE assessment is achieved through quantifying the SEE rates in avionics systems in accordance with IEC 62396-1, based on:

a) the atmospheric neutron environment;

b) the components in a given system; and

c) the SEE response of those components to energetic neutrons."

IEC TS 62239-1 also contains an appendix that describes the various mitigations that could be applied at the following levels:

1. Component (e.g., microcircuit, diode, transistor, connector, etc.).;
2. Module or PCB;
3. Original Equipment Manufacturer (OEM) delivered unit;
4. Aircraft, Unmanned Aerial Vehicle (UAV), or satellite bay;
5. Aircraft, UAV, satellite, or space unit;
6. Aircraft, UAV, satellite or space unit external.

IEC TS 62239-1 is a parts management requirements document that includes requirements for atmospheric radiation, parts obsolescence, lead-free electronics, and other related issues.

It is recommended that the requirements and guidance to normalize the process for certification analysis with respect to SEE be incorporated into a high-level document used in the certification process. The atmospheric radiation section(s) of that document could, in turn, reference many of the standards and specifications reference in this report.

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2.5.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AEH	Airborne Electronic Hardware
AFE	Authorization for Expenditure
AFE 72	Mitigating Radiation Effects R&D Project
ARP	Aeronautical Recommended Practice
AVSI	Aerospace Vehicle Systems Institute
CMOS	Complementary-metal-oxide-semiconductor
COTS	Commercial-off-the-Shelf
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FPGA	Field-programmable Gate Array
IC	Integrated Circuit
IEC	International Electrotechnical Commission
JEDEC	Joint Electron Devices Engineering Council
JESD	JEDEC Standard
MBU	Multiple Bit Upset
MCU	Multiple Cell Upset
MeV	Million-Electron-Volts
NASA	National Aeronautics and Space Administration
n/cm^2	Neutron Differential Flux
nm	Nanometer
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory

PCB	Printed Circuit Board
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
SEB	Single Event Burn-out
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SET	Single Event Transient
SEU	Single Event Upset
Si	Silicon
TC	Technical Committee
TS	Technical Specification
UAV	Unmanned Aerial Vehicle
WG	Working Group

2.6 Limited-life Semiconductors Issue Overview

Feature sizes of complex complementary-metal-oxide semiconductor (CMOS) devices, such as microprocessors, memories, and Field-programmable Gate Array (FPGA)s, are now in the range of 10-22 nm, and continue to shrink. Traditionally, aerospace users of such devices have assumed that

(1) the devices have lifetimes that are essentially infinite with respect to the expected lifetimes of the Airborne Electronic Hardware (AEH) in which they operate; and

(2) AEH applications would trail significantly behind the cutting edge of CMOS and other semiconductor device technology.

Those assumptions, however, are no longer accurate. Both the global electronics industry and the aerospace industry now acknowledge that the service lifetimes of semiconductor devices are short enough to be of concern, and must be accounted for in AEH system design, and in the certification process [1-3].

2.6.1 Limited-life Semiconductors Issue Details

Semiconductor devices used in AEH hardware are targeted for markets other than aerospace; and the designers and manufacturers of those devices are driven by forces such as lower costs, higher performance, and short time to market. This results in shorter production and in-service lifetimes than would be desired by AEH users. AEH priority concerns, such as reliability and long service life, are relatively less important to the majority of semiconductor manufacturers, for whom reliability, configuration control, and the methods to achieve them, are defined in terms of what is best for the target market, and not what is best for AEH. One of the outcomes is that AEH designers and manufacturers are likely to use semiconductor devices with service lifetimes that are significantly shorter than the traditional design life of the AEH hardware. Some semiconductor devices can be expected to "wear out" in 5-10 years or less under AEH operating temperatures, duty cycles, and other operating conditions. This trend is becoming more troublesome as semiconductor device feature sizes continue to decrease below 50 nanometers (nm).

The major "wearout" mechanisms of concern at these deep sub-micron feature sizes are

(1) electromigration (EM),

(2) hot carrier injection (HCI),

(3) time-dependent dielectric breakdown (TDDB), and

(4) negative bias temperature instability (NBTI).

EM results in either open circuit failures or unintentional short circuits due to movement of metal atoms in the conductors of the silicon device; while HCI, TDDB, and NBTI are failures in the gate oxide, resulting in threshold voltage shift and performance degradation. Slow degradation in performance leads to decreased timing margins, and finally incorrect functionality in the semiconductor device. The locations of these mechanisms are illustrated in Figure 3.

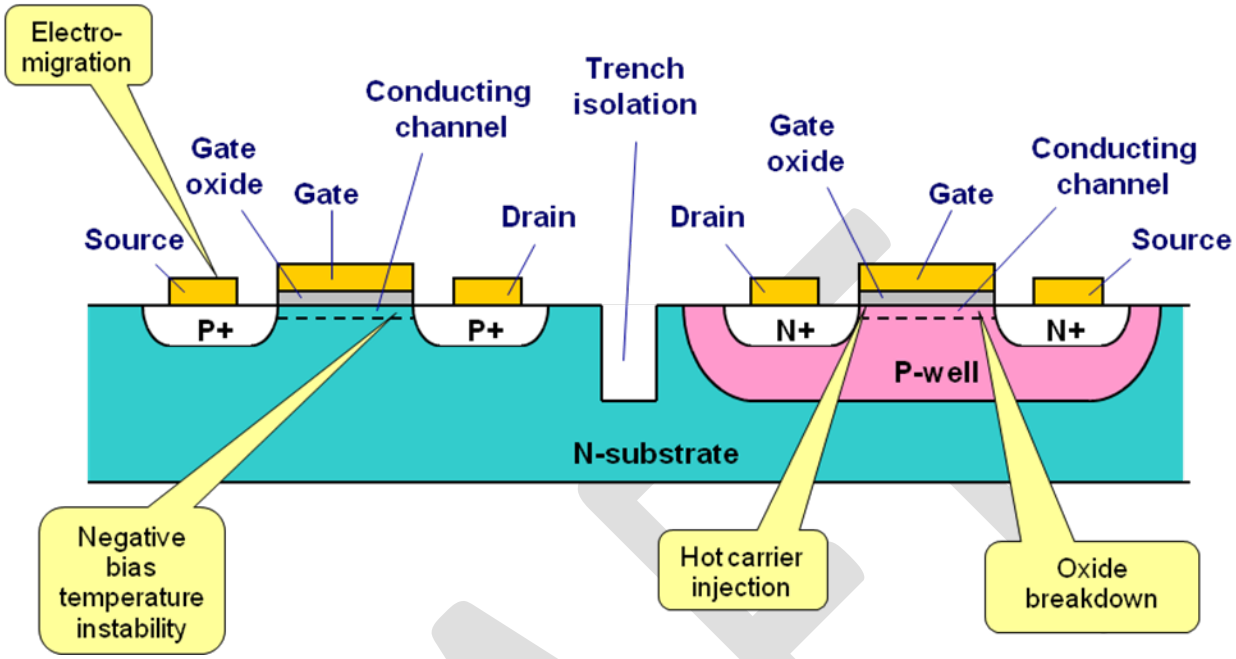

Figure 3. Semiconductor wearout mechanisms.

$$AF_{EM} = \left(\frac{f_1}{f_2}\right)^n \left(\frac{V_{dd1}}{V_{dd2}}\right)^\gamma e^{\left(\frac{E_a}{k} * \frac{T_1 - T_2}{T_1 T_2}\right)}$$

$$AF_{HCI} = e^{\left(\gamma * \frac{V_{ds1} - V_{ds2}}{V_{ds1} V_{ds2}}\right)} e^{\left(\frac{E_a}{k} * \frac{T_1 - T_2}{T_1 T_2}\right)}$$

$$AF_{NBTI} = \left(\frac{V_{gs1}}{V_{gs2}}\right)^\gamma e^{\left(\frac{E_a}{k} * \frac{T_1 - T_2}{T_1 T_2}\right)}$$

$$AF_{TDDB} = \frac{V_{gs1}^{(a+bT_1)}}{V_{gs2}^{(a+bT_2)}} e^{\left(c * \frac{T_1 - T_2}{T_1 T_2} + d * \frac{T_1^2 - T_2^2}{T_1^2 T_2^2}\right)}$$

Table 2.6-1. Acceleration models

Each failure mechanism is driven by a combination of temperature, voltage, current, frequency, and duty cycle. Semiconductor device manufacturers have developed equations to model each of the four major mechanisms; but those models are highly proprietary, and often are specific to a given manufacturer or technology node.

2.6.2 Relationship to safety and certification

Up to the present time, semiconductor device wearout lifetimes have been assumed to be long enough that they do not impact the design life of AEH systems, and thus if the normal parametric and environmental considerations are addressed in the design, the device lifetime need not be addressed specifically in the certification process. In future design implementations this will not be the case.

Wearout models are expensive to develop, and require expertise for their successful application. Such expertise typically has not been available to the AEH system design process, and therefore must be developed and updated as technology continues to progress. It is necessary to conduct additional testing, ideally in cooperation with device manufacturers, to develop the confidence in the models and to justify their use in the AEH design and certification processes.

Details associated with this issue will continue to morph and change as technology continues to progress. Due to its complexity, and the costs associated with methods to address the life-limited semiconductor issue, the aerospace industry needs to develop consensus on a common set of methods to address it in system design and certification. Furthermore, there needs to a consensus-driven approach to updating these methods as semiconductor device technology continues to progress.

2.6.3 Existing activity

The models used by semiconductor device manufacturers are not normally available to the users of the devices. It is possible, however, to develop "generic" models based on published literature, and that has been done by DfR Solutions, working under contract to AFE 71, supplement 1 [1, 2]. The models are shown in Table 2.6-1. That work is continuing in AFE 83, which is developing spreadsheets containing "default" models that can be used by AEH system designers and certification specialists with a basic knowledge of the issue.

In the early 2000s, some AEH manufacturers initiated discussion with some of the major commercial semiconductor device manufacturers, who indicated that they had information that would be useful to AEH users; and they would be willing to share such information, provided the proper vehicle for such sharing data, and incentives to do so, could be made available. In this regard, the aerospace industry published two documents [4, 5]. This effort produced no tangible results, and the two documents currently do not adequately define the information needed to address this issue.

AFE 71 initiated discussions with key semiconductor device manufacturers and semiconductor industry groups, regarding the information needed from the device manufacturers to support AEH needs, and these discussions are continuing in AFE 83. Aside from some very encouraging responses from a few semiconductor device manufacturers, no concrete results have yet been attained on the scale necessary to support AEH needs.

Based on the results of past efforts by the AEH industries to communicate their needs to semiconductor device manufacturers, and on the relative unimportance of AEH customers to semiconductor device manufacturers, it is not likely that the level of communication and data exchange between the two industries will satisfy all the needs of the AEH industries. These efforts will continue, but the most likely path to success in addressing this issue is for the AEH industries to develop and used their own generic models, based on the best technical information available.

2.6.4 Technology weakness/deficiency

Semiconductor technology is progressing at a rate that makes it difficult for AEH system designers and certification agencies to accommodate it. Because the issue of life-limited semiconductors is technically complex, and dynamic, the expertise to deal with it generally does not exist in the AEH industry.

2.6.5 Process weakness/deficiency

There currently is no consensus on a feasible set of methods to address the issue of life-limited semiconductor devices in the AEH system design and certification process.

2.6.6 Recommendations/desired outcome

The following "solution elements" need to be in place to address the limited-life semiconductor issue:

1. **AEH System Design, Production and Support.** AEH manufacturers need to have access to data and other information needed to address the limited-life semiconductor issue in the AEH system design, production, and support phases.
2. **AEH System Certification.** Certification authorities need to have sufficient knowledge and information to evaluate applicants' data submissions with regard to limited-life semiconductors; and there needs to be adequate documentation to assure that the certification process is conducted effectively and consistently for all AEH systems.
3. **AEH Procurement.** AEH procurement documents, such as Specification Control Drawings (SCD)s, Statement of Work (SOW), or other contract language need to include requirements to ensure that the life-limited semiconductor issue is addressed adequately by AEH manufacturers. If necessary, aerospace industry standards must be developed and/or revised for this purpose.

AFE 75 recommends that International Electrotechnical Commission (IEC) TC107 [6] and/or SAE International (SAE) Avionics Process Management Committee (APMC) [7] develop standard to address life-limited semiconductor devices in AEH system design and that IEC and SAE consider producing a single document to avoid the inevitable divergence of two standards over time.

AFE 75 recommends that certification authorities and avionics system customers, e.g., Department of Defense (DoD) and platform integrators, adopt IEC TC 107 and/or SAE APMC committe standards after they are released.

2.6.7 References

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2. Wyrwas, E. J., and Bernstein, J. B., "Quantitatively Analyzing the Performance of Integrated Circuits and Their Reliability," IEEE Instrumentation & Measurement Magazine, February 2011, pp. 24-31.
3. Mesgarzadeh, B., Soderquist, I., and Alvandpour, A., "Reliability Challenges in Avionics due to Silicon Aging," 15th IEEE International Symposium on Design and Diagnostics of Electronic Circuits and Systems, DDECS", Tallinn, Estonia, April 18-20, 2012, pp.342-347.
4. TechAmerica, GEIA-STD-0002-1, Aerospace Qualified Electronic Component (AQEC) Requirements, Volume 1 – Integrated Circuits and Semiconductors." August 1, 2005

5. International Electrotechnical Commission/Technical Specification, IEC/TS 62564, Process management for avionics – Aerospace qualified electronic components (AQEC) - Part 1: Integrated circuits and discrete semiconductors." Edition 2.0, August 2011
6. International Electrotechnical Commission (IEC) Technical Committee (TC) 107, "Process Management for Avionics", http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1304, Last accessed 10/27/2013
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2.6.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section.

AEH	Airborne Electronic Hardware
AFE 71	Reliability Prediction Software
AFE 83	Semiconductor Reliability
APMC	Avionics Process Management Committee
AQEC	Aerospace Qualified Electronic Components
CMOS	Complementary-Metal-Oxide-Semiconductor
DDECS	Design and Diagnostics of Electronic Circuits and Systems
DfR	DfR Solutions
DoD	Department of Defense
EM	Electromigration
FPGA	Field-programmable Gate Array
GEIA	Government Electronics and Information Technology Association
HCI	Hot Carrier Injection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers

IMAPS	International Microelectronics Assembly and Packaging Society
JEDEC	Joint Electronic Device Engineering Council
JESD	JEDEC Standard
NBTI	Negative Bias Temperature Instability
nm	Nanometers
SAE	Society of Automotive Engineers
SCD	Specification Control Drawing
SOW	Statement of Work
STD	Standard
TDDB	Time dependent dielectric breakdown
TC	Technical Committee
TS	Technical Specification

2.7 Outdated Reliability Assessment Methods

2.7.1 Description of the Issue

Existing guidance for predicting the reliability of aerospace, defense, and high performance (ADHP) electronic systems is outdated and unmanaged. This can lead to inaccuracies in predictions and to a variety of methodologies that interpret the available guidance. This applies to both custom and commercial-off-the-shelf (COTS) electronics, however COTS electronics suffer from the additional concern that the avionics system developer often does not have a detailed knowledge of the components of a COTS component or assembly. This can be hierarchical throughout the supply chain: subsystem supplier may protect their Intellectual Property (IP) by supplying a "black box," while at the same time incorporating components for which they have incomplete knowledge of the detailed design. Thus a set of reliability prediction methodologies is needed that (1) ensures consistent application of analyses, (2) is broadly adopted, (3) provides improved accuracy, (4) is comprehensive enough to maintain consistency for a broad range of avionics technologies that are integrated into systems, (5) is maintainable to keep pace with changes in commercial technologies, and (6) is applicable to both custom and COTS components.

In the 1950's, electronics reliability models were derived and standardized by the Department of Defense (DoD) through the analysis of historical failure data. In 1961, the first edition of MIL-HDBK-217 [1] was published, providing a basic reliability analysis tool that is still in use today (although it has undergone several revisions). In 1994, U.S. Secretary of Defense William Perry published his pivotal memorandum titled "Specifications & Standards - A New Way of Doing Business." [2] This memo, and the changes in military acquisition that followed, caused many military standards to be cancelled in favor of commercial standards and practices. A consequence of this memo is that DoD stopped updating MIL-HDBK-217, and started looking to industry organizations to provide updated reliability prediction methods.

The most recent revision of MIL-HDBK-217 is dated February 28, 1995, and although clearly obsolete, some of the basic assumptions used for electronic components are still applicable. For this reason, a complete revision of every model in the handbook may not be necessary or cost-effective. It is, however, important to update some models, and maybe the framework of the document itself, to accommodate the rapidly changing electronics supply chain, especially with respect to COTS components, assemblies, and equipment.

A major weakness of MIL-HDBL-217 and other "bottom-up" reliability prediction methods is their total focus on part failures as causes of system failures, neglecting other causes such as system design, maintenance practices, operational misuse, etc. In contrast, SAE ARP 5890A [3] takes a "top-down" approach, in which reliability data from a similar predecessor product in a similar application are analysed to produce a system reliability assessment. If no sufficiently similar predecessor product is found, then the process uses successively lower-level assemblies, sub-assemblies, or components, until one is found. If no such lower-level predecessor products are found, then the process becomes a "bottom-up" approach.

2.7.2 Relationship to safety and certification

Reliability predictions have been used by Airborne Electronic Hardware (AEH) system producers and users for many purposes, including system design, system architecture, reliability analysis, trade studies, safety analysis, availability analysis, spares planning, redundancy modeling, Failure Modes and Effects Analysis (FMEAs), scheduled maintenance planning, and product warrantees and guarantees.

Typical safety and certification analyses involve system level methods such as Fault Tree Analysis (FTA), FMEA, Failure Mode Effects and Criticality Analysis (FMECA), etc. Most of these methods work with inputs regarding failure rates derived, if possible, from in-service expereience. In view of today's rapidly-changing component technologies, it is unrealistic to expect that in-service data will be available in the timely manner required for certification and safety analyses of new systems.

2.7.3 Existing activity

The Defense Standardization Program Office (DSPO), working through the Naval Surface Warfare Center (NSWC) Crane, is the preparing and maintenance authority for MIL-HDBK-217. In 2008, NSWC Crane launched an effort to revise MIL-HDBK-217, and convened an industry working group to review and propose changes to the handbook. The initial phase of this effort was to provide an update to key reliability parameters, but not include new models. It was anticipated that future phases of the NSWC Crane led effort would develop a fundamentally new approach, using physics of failure modelling methods.

The DSPO also sponsored aerospace industry collaborative research through the Aerospace Vehicle Systems Institute (AVSI). Much of this research has been focused on mitigating the effects of atmospheric radiation; and on understanding and mitigating the effects on microcircuit reliability and service life, as semiconductor technology progresses below 100-nanometer feature sizes. This research resulted in advances in physics of failure based modelling of semiconductor wearout mechanisms, and has produced results that should be captured in AHP system reliability analyses.

Subsequent AVSI research projects considered the need for a broader set of integrated issues than just the incorporation of semiconductor physics of failure models in the existing reliability guidance. These efforts led to an industry consensus reliability roadmap [4] that identified a number of perceived gaps in existing reliability methodologies. The features desired in an integrated set of reliability prediction methodologies were identified and prioritized by a broad representation of the US aerospace industry using a quality functional deployment formalism to ensure that multiple perspectives were represented in the resulting roadmap. This roadmap has been presented at a number of conferences in order to continue with a representative, consensus-based approach to developing a broadly adopted, coherent, accurate, and integrated set of reliability prediction methodologies for AEH suppliers and integrators.

2.7.4 Technology weakness/deficiency

The currently-used methods for AEH system reliability predictions are outdated and inaccurate. Due to the long development cycle times for AEH, compared to that for commercial electronics, it is increasingly unrealistic to accumulate sufficient in-service data in time to have it available

for the design and certification process. This is especially true of the commonly-used "bottom-up" methods.

2.7.5 Process weakness/deficiency

Despite the widespread distrust of currently-used methods, there is no consensus on any type of replacement for them. This has led to cynicism about any reliability prediction process or data, and often there is no discernible process or data for a given product or program.

2.7.6 Recommendations / desired outcome

A current AVSI Project (AFE 80) is continuing the maintenance and update of the reliability roadmap. This project supports other projects with a detailed framework for the reliability modeling approach, including many of the features of the Roadmap that are common to all reliability modeling approaches, such as common standards for establishing models, application of models, testing, data collection and validation. AFE 80 explores ways to assure periodic maintenance and update of the models. In addition, AFE 80 investigates the feasibility and establishes ground rules for implementing a reliability prediction methodology electronically rather than as a static, published document.

This documented framework includes:

1. Establishing New Reliability Models
    a. Standards for the progress of subprojects
    b. Typical progression of tasks
    c. Common rules for engaging and proposing a model
    d. Checklist for Subproject launch
2. Application of Reliability Models
    a. Common rules for using models
    b. Calibration
    c. Levels of detail needed for different applications
    d. Criteria for modeling environmental effects
    e. Address complexities in the Natural Environment
3. Validation
    a. Define what it means to be "validated" (versus demonstrated)
    b. Standards for testing and analyses
    c. How much field data is enough (agree on statistical tests)
4. Mechanism for review and update of models
    a. Ongoing maintenance of models
    b. Ground rules for periodic updates
    c. Use of field data
5. Electronic based methodology
    a. Issues to resolve (e.g. configuration control) to achieve an accelerated (over paper publication) but still deliberate process

b. Vetting of new contributions
c. Processes for updating
d. Usage standards, user policy
e. Defaults

The work described above is focused on the "bottom-up" approach. As noted earlier, SAE ARP 5890A takes a "top-down" approach, and is being used successfully by a number of avionics manufacturers and users, especially those in the electronic engine controls segment of the industry. (ARP 5890A was published, and is maintained by SAE committee E-36, electronic engine controls.) Due to its inherently more comprehensive and logical approach to reliability assessment, it deserves greater consideration by a wider range of avionics manufacturers and customers, and also for use in the certification process.

Any solution to the inadequacy of existing reliability guidance and methodologies must provide incentives for ADHP stakeholders across the globe to work together to:

1. Provide a focus organization (preferable a standards organization such as International Electrotechnical Commission (IEC) or SAE, that includes all stakeholders, to provide visibility into all reliability-related work for the ADHP industries, including standards publication and maintenance, and related research;
2. Work with ADHP customers and regulatory agencies to provide the incentives for manufactures and suppliers of ADHP systems to develop and use consistent reliability methods;
3. Harmonize reliability methods on a global basis;
4. Encourage ADHP stakeholders to prioritize improvements in accuracy and consistency to effect cost savings and improved designs,
5. Advise reliability engineers at all levels of the ADHP supply chain to adopt best-practices in implementing the reliability prediction methodologies.

AFE 75 recommends the use of ARP-5890A for reliability assessment and certification process. The FAA AC 20-157, HOW TO PREPARE A RELIABILITY ASSESSMENT PLANS FOR AIRCRAFT SYSTEMS AND EQUIPMENT [5] refers to ARP-5890.

AFE 75 recommends the FAA update AC 20-157 to recognize ARP-5890A.

AFE 75 further recommend the ownership of the document be transfered from SAE Committee E-36 to SAE APMC [6].

2.7.7 References

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2.7.8 Acronyms and abbreviations

The following acronyms and abbreviations are used in this section.

AC	Advisory Circular
ADHP	Aerospace, Defense, and High Performance
AEH	Airborne Electronic Hardware
AFE	Authorization for Expenditure
AFE 80	Integrated Reliability project
APMC	Avionics Process Management Committee
ARP	Aeronautical Recommended Practice
AVSI	Aerospace Vehicle System Institute
COTS	Commercial-off-the-Shelf
DoD	Department of Defense
DSPO	Defense Standardization Program Office
FMEA	Failure Mode Effects Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FTA	Fault Tree Analysis
HDBK	Handbook
IEC	International Electrotechnical Commission
MIL	Military
NSWC	Naval Surface Warfare Center
SAE	Society of Automotive Engineers

2.8 Transition to Lead-free Electronics

The transition to a lead-free environment is clearly among the issues and threats that AFE 75 has considered as potentially impacting safety.

The transition to lead-free electronics throughout the globe has resulted in a serious increase in the threat to aviation electronics reliability, and it is difficult if not impossible to quantify the risk.

To ensure that a system meets all its safety and reliability requirements, potential system failures due to the transition to lead-free electronics should be considered as an element of the design.

2.8.1 Description of the issue

In 2002, the European Union issued a directive (EU Directive 2002/95/EC) [1], which required that new electrical and electronic equipment and systems put on the market after 1 July 2006 shall not contain lead (Pb) or other environmentally hazardous materials. In response to this directive, and legislation resulting from it, the global electronics industry is undergoing a transition from tin-lead (SnPb) to lead-free (Pb-free) assembly alloys and termination finishes. Although aerospace generally has been excluded from the directive and legislation, it has been "swept along" as the global electronics supply base makes the transition, and therefore must accommodate the use of lead-free electronics.

Traditionally, lead has been used as a surface plating for soldering purposes (e.g. tin/lead solder alloys) on discrete electrical and electronic components, including integrated circuits, semiconductors, capacitors, resistors, and other electronic circuitry. Currently the largest volume of lead in many of these electronic assemblies is in the tin-lead (Sn-Pb) eutectic and near eutectic alloys used in wiring, printed circuit board assemblies, wiring harnesses, and electrical and electronic equipment and systems.

The aerospace electronics, with its unique environmental and qualification requirements, is impacted in the following five key areas:

Solder Joint Reliability/Line Replaceable Units (LRU) Qualification:

No consensus currently exists regarding assurance of reliability of solder joints made with the various lead-free assembly alloys used commonly in electronics assemblies. This is further complicated that a variety of alloys currently are in use, and new ones are introduced as development continues. Aerospace electronic and electrical products can be critical elements in the safety of the aircraft. In addition, material changes in LRUs that may affect the reliability of the product can require re-qualification of the product.

Tin Whisker Susceptibility:

In the near term, particularly during the transition to lead-free electronics, one of the more significant threats to proper operation is tin whisker susceptibility. A common replacement for lead in electronic component termination finishes is pure tin, which is known to produce tin whiskers. Tin whiskers are conductive growths that can cause electrical shorts in aerospace electronic equipment. At present this phenomenon is not clearly understood, and no known solutions exist to completely preclude tin whisker growth.

Maintenance/Repair Methodology:

As the transitions to lead-free electronics continues, it is vitally important to maintain proper maintenance procedures and materials. As of this writing, there is no single or universal material solution for the replacement of Sn-Pb solder and finish. In addition, at this point it is not clear that the mixing of each of various materials results in a reliable solder joint.

The manufacturer must clearly call out maintenance and repair methodologies so that all maintenance shops can follow proper steps in their processes.

Configuration Control:

One of the more difficult issues identified at this time by the above referenced working groups is that of configuration control. As the component manufacturers are transitioning to lead-free finishes, they are not consistently, if at all, identifying the new finish materials. This has led to a configuration control difficulty for the aerospace industry. Aerospace has rather strict policies and procedures for configuration control, and those must be adhered to for part termination and assembly alloys.

Component Availability:

The availability of components as it relates to the transition to lead-free electrical/ electronic components appears to be a primary link to the configuration control issue. It is not obvious that the transition to lead-free electronics will in itself cause component obsolescence, but it will lead to unavailability of Sn-Pb based components.

2.8.2 Relationship to safety and certification

Methods to address the lead-free environment in the Airborne Electronic hardware (AEH) design, development, and certification processes should be developed and incorporated into those processes. The methods should include test, analysis, and other processes to determine the potential impact on the safety and airworthiness of the system. The certification process should be modified to assess the use and effectiveness of the methods.

To ensure a system meets all its safety and reliability requirements, potential system failures that are the result of the lead-free environment need to be considered as an element of the design.

Test protocols that have been traditionally used in qualifications tests may or may not be appropriate protocols to determine if the new materials will withstand rigorous aerospace and avionics environments. Product performance needs to be reviewed periodically and supported by root cause analysis of any field failures to validate or improve test protocols.

Pb-free solders and finishes may decrease the reliability of systems or subsystems. The following may impact safety and system performance:

- Pb-free solders may be common in commercial-off-the-shelf (COTS) piece parts.
- SnPb solders and finishes on assembly piece parts may be difficult to procure.
- SnPb solders and finishes may not be available regardless of contract or specification.
- SnPb versus Pb-free piece parts may be difficult to identify in pre-assembled subsystems.
- System production and maintenance personnel may inadvertently mix SnPb and Pb-free solders which may be incompatible.

2.8.3 Existing activity

The Lead-free Electronics in Aerospace Project Working Group (LEAP WG) [2] was formed in 2004, sponsored jointly by the Aerospace Industries Association (AIA), the Avionics Maintenance Conference (AMC), and Government Electronics and Information Technology Association (GEIA). The task of the LEAP WG was to address aerospace issues related to the global elimination of lead from electrical and electronic equipment put on the market after July 1, 2006.

The LEAP WG was superseded by the Pb-free Electronics Risk Management (PERM) Consortium, sponsored by the Institute for Interconnecting and Packaging Electronic Circuits (IPC) [3].

Their major LEAP-PERM deliverables are standards and handbooks to assist and guide industry in the transition to lead-free solder and finishes. These documents are currently the best resource for guidance in the transition to lead free avionics and they are listed in Table 3. See reference list in 2.8.7 for alternate reference sources.

Table 3. Standards and Handbooks for Lead-free transition

GEIA-STD-0005-1	**Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder [4]**	Used by aerospace electronic system "customers" to communicate requirements to aerospace electronic system "suppliers"
GEIA-STD-0005-2	**Standard for Mitigating the Effects of Tin Whiskers in Aerospace In High Performance Electronic Systems [5]**	Used by electronic system "suppliers" as a guide in the design and evaluation of designs that need to be robust to the effects of tin whiskers
GEIA-STD-0005-3	**Performance Testing for Aerospace and High Performance Electronic Interconnects Containing Lead-Free Solder and Finishes [6]**	Used by aerospace electronic system "suppliers" to develop reliability test methods and interpret results for input to analyses
GEIA-HB-0005-1	**Program Management / Systems Engineering Guidelines For Managing The Transition To Lead-Free Electronics [7]**	Used by program managers to address all issues related to lead-free electronics, e.g., logistics, warranty, design, production, contracts, procurement, etc.
GEIA-HB-0005-2	**Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder and Finishes [8]**	Used by aerospace electronic system "suppliers" to select and use lead-free solder alloys, other materials, and processes. It may include specific solutions, lessons learned, test results and data, etc.
GEIA-HB-0005-3	**Repair and Rework of Aerospace and High Performance Electronic Systems Containing Lead-Free Solder [9]**	Used by technicians and the planners in the repair and rework end of the life cycle to assure that the proper techniques are followed

In 2009, the Lead-free Manhattan Project convened a group of subject matter experts from aerospace and defense was convened to identify the key risks associated with lead-free solder in

high reliability and safety critical systems. The cost to close the knowledge gaps for using lead-free electronics in these applications was estimated at $105M [10, 11].

2.8.4 Technology weakness/deficiency

To date, no single lead-free alloy is a drop-in replacement for the tin-lead (Sn-Pb) eutectic alloys in widespread use in electronic and electrical industry over the last 50 plus years. Eutectic tin-lead (melting point 183 °C), and near-eutectic alloys have been the predominant in electronics/electrical assemblies. Many of the proposed alternative materials have higher melting points than current eutectic Sn-Pb, while some of the lower-temperature materials will not be able to withstand the extreme aerospace and aviation operating environments.

Most of the commonly-used alloys require higher processing temperatures that can result in damage to the printed circuit board and/or components. Reliability testing methods for lead-free alloys are still being developed. Results from thermal cycling reliability testing conducted to date, comparing lead-free to Sn-Pb alloys have yielded inconclusive results for aerospace applications of lead-free alloys. The results have shown that some alloys in mild environmental conditions are more reliable, while the same alloys are much less reliable in harsher environments. Thus depending upon the lead-free alloy type and the application, tests have shown that their useful life may be shortened due to greater fatigue than the Sn-Pb alloy for which it is substituted. In addition to the lack of consensus from lead-free thermal cycling tests; there is little vibration and shock modeling or durability test data available for the lead-free alloys.

Another risk associated with the use of lead-free components, especially on printed circuit boards, is the need for processing temperatures, which exacerbate coefficient of thermal expansion (CTE) mismatches, which could reduce component service life in comparison to Sn-Pb components. Another risk is that lead contamination can negatively influence the properties of lead-free solders. For example, if a printed circuit board (PCB) was originally manufactured with Sn-Pb solder, and during a repair operation the Sn-Pb solder was not adequately removed, then the introduction of Pb-free solder with certain alloys may result in a flawed solder joint.

2.8.5 Process weakness/deficiency

Some avionics products already contain components with pure tin termination finishes, as well as other lead-free finishes. So far, there have been no identified failures related to the introduction of these lead-free finishes; but it is acknowledged that the test protocols that have been traditionally used in these qualifications tests may or may not be appropriate protocols to determine if the new materials will withstand the rigorous aerospace and avionics environments.

2.8.6 Recommendations / Desired Outcome

The research to address the issues raised by the Lead-free Manhattan project [10, 11] has not been funded. AFE 75 supports the efforts of PERM and others to obtain this funding; without taking the lead in the effort.

AFE 75 endorse the cited references published by IEC TC107 [12] and SAE APMC [13] and recommends that the International Electrotechnical Commission (IEC) and SAE, International consider producing a single set of lead-free documents.

AFE 75 recommends that certification authorities and avionics system customers, e.g., Department of Defense (DoD) and platform integrators, adopt IEC TC 107 and/or SAE Avionics Process Management Committee (APMC) committee standard for lead-free electronics.

2.8.7 References:

1. Directive 2002/95/EC of the European Parliament and of the Council, "The Restriction of the use of certain Hazardous Substances in electrical and electronic equipment," January 27, 2003.
2. Lead-free Electronics in Aerospace Project (Leap), Working Group (WG), Aerospace Industries Association (AIA), the Avionics Maintenance Conference (AMC) and the Government Electronics and Information Technology Associates, http://www.aia-aerospace.org/assets/wp_leap-wg_1106.pdf , last accessed 4/12/2014
3. Pb-free Electronics Risk Management (PERM) Consortium, http://www.ipcoutlook.org/mart/51458F.shtml , Last Accessed 4/12/2014
4. TechAmerica Standard, GEIA-STD-0005-1-A, "Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder", March 1, 2012. *(Alternate: IEC/TS 62647-1 edition1.0, "Process management for avionics - Aerospace and defence electronic systems containing lead-free solder - Part 1: Preparation for a lead-free control plan," August 2012.)*
5. TechAmerica Standard, GEIA-STD-0005-2A "Standard for Mitigating the Effects of Tin Whiskers in Aerospace In High Performance Electronic Systems," May 1, 2012. *(Alternate: IEC/TS 62647-2 edition1.0,"Process management for avionics - Aerospace and defence electronic systems containing lead-free solder - Part 2: Mitigation of deleterious effects of tin," November 2012)*
6. TechAmerica Standard, GEIA-STD-0005-3-A,"Performance Testing for Aerospace and High Performance Electronic Interconnects Containing PB-free Solder and Finishes," March 1, 2012.
   (Alternate: International Electrotechnical Commission/Publically Available Specification, IEC/PAS 62647-3 edition 1.0,"Process management for avionics - Aerospace and defence electronic systems containing lead-free solder - Part 3: Performance testing for systems containing lead-free solder and finishes," July 2011.")
7. TechAmerica Handbook, GEIA-HB-0005-1, "Program Management / Systems Engineering Guidelines For Managing The Transition To Lead-Free Electronics," June 20, 2006 *(Alternate: International Electrotechnical Commission/Publically Available Specification, IEC/PAS 62647-21 edition 1.0,"Process management for avionics - Aerospace and defence electronic systems containing lead-free solder - Part 21: Program management - Systems engineering guidelines for managing the transition to lead-free electronics," July 2011.)*
8. TechAmerica Handbook, GEIA-HB-0005-2,"Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder and Finishes," November 2007.
   (Alternate: International Electrotechnical Commission/Publically Available Specification, IEC/PAS 62647-22 edition 1.0, "TC/SC 107, Process management for avionics - Aerospace

and defence electronic systems containing lead-free solder - Part 22: Technical guidelines," July 2011.)

9. TechAmerica Handbook, GEIA-HB-0005-3,"Rework/Repair Handbook to Address the Implications of Lead-Free Electronics and Mixed Assemblies in Aerospace and High Performance Electronic Systems," September 1. 2008
(Alternate: International Electrotechnical Commission/Publically Available Specification, IEC/PAS 62647-23 edition 1.0,"Process management for avionics - Aerospace and defence electronic systems containing lead-free solder - Part 23: Rework and repair guidance to address the implications of lead-free electronics and mixed assemblies," July 2011.)
10. "The Lead-free Electronics Manhattan Project Reports," Phase 1, U.S. Government Contract No. N00014-08-D-0758, Benchmark Center of Excellence, ACI Technologies, 2009.
11. "The Lead-free Electronics Manhattan Project Reports," Phase 2, U.S. Government Contract No. N00014-08-D-0758, Benchmark Center of Excellence, ACI Technologies, 2010.
12. International Electrotechnical Commission (IEC) Technical Committee (TC) 107, "Process Management for Avionics", http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1304, Last accessed 10/27/2103
13. SAE, International "Avionics Process Management Committee" (APMC), http://www.sae.org/works/committeeHome.do?comtID=TEASSTCAPMC, last accessed 4/12/2014

2.8.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

ACI	ACI Technologies, Inc.
AEH	Airborne Electronic hardware
AFE	Authorization for Expenditure
AIA	Aerospace Industries Association
AMC	Avionics Maintenance Conference
APMC	Avionics Process Management Committee
COTS	Commercial-off-the-Shelf
CTE	Coefficient of Thermal Expansion
DoD	Department of Defense
EC	European Council
EU	European Union
GEIA	Government Electronics and Information Technology Association
HB	Handbook

IEC	International Electrotechnical Commission
IPC	Institute for Interconnecting and Packaging Electronic Circuits
LEAP	Lead-free Electronics in Aerospace Project
LRU	Line Replaceable Unit
Pb	Lead
PAS	Publically Available Specifications
PCB	Printed Circuit Board
PERM	Pb-free Electronics Risk Management
SAE	Society of Automotive Engineers
Sn	Tin
SnPb	Tin/Lead
STD	Standard
TC	Technical Committee
TS	Technical Standard
WG	Working Group

2.9 Availability and Updates of Errata

2.9.1 Description of the issue

Complex Commercial-off-the-Shelf (COTS) components can have unseen functional behavior that may not be revealed until their actual usage in industry. As a result, component manufacturers need to notify their customers of issues and provide suggested work-arounds by publishing an errata document. A component's well-maintained errata document allows a new product design to capitalize on the previous industry usage of a complex COTS component. Most processor manufacturers have a well-defined errata practice and format that has evolved over years of development. This same approach is expected for other types of complex COTS components. Since there is no guiding standard for what constitutes a good errata document, this section will be used to establish expectations for a complex COTS component's errata, using existing processor errata as a guide.

2.9.2 Relationship to safety and certification

A regularly updated errata document for a complex COTS component is important to the safe operation of avionics equipment because it notifies users of bugs and fixes found by other users. Errata updates and the notification process continues well after the avionics system is in production and in service. For example, errata updates for a processor typically continue for years after the part is productionized.

2.9.3 Existing activity

The European Aviation Safety Agency (EASA) Certification Memorandum (EASA CM – SWCEH – 001) - Section 9.3.4 [1] mentions that the applicant should show how the component manufacturer captures, maintains, and publishes errata. It also wants to see trending evidence of a decrease in rate of occurrence of new errata updates over time (to establish component maturity).

2. 9.4 Technology weakness/deficiency

Whenever a COTS component becomes so complex that it cannot be completely tested before production, it also utilizes customer in-use validation. These types of components should have an errata policy to support and track this continued validation. In the past, mainly processors fell into this group, but now many other complex COTS components should be included (and in many cases they already have errata being published). Peripheral Component Interconnect Express (PCIe) switches, Serial Rapid I/O (sRIO) switches, Universal Serial Bus (USB) or

Secure Data (SD) Card controller chips, and Ethernet Media Access Controls (MACs) are examples of complex COTS components that need an errata document.

2.9.5 Process weakness/deficiency

It is obvious that processors need an errata document, but when do other COTS components become complex enough to require a published and regularly updated errata?

There is no formal guidance on what constitutes a well written and complete errata document. There should be a list of minimum content necessary in a published errata document.

The frequency of updates to the errata document and how long it takes before a known issue gets incorporated into the next errata revision are also important in assessing the errata of a COTS component.

2.9.6 Recommendations/desired outcome

AFE 75 recommends a revision to SAE EIA-4899 [2] & IEC/TS 62239-1[3] standards. The revision should contain an evaluation of the quality of the errata document as discussed in the tables below. Table 4 shows the expected content of an errata document and the associated question. Table 5 shows the questions we recommend be addressed when a given complex COTS component that does not have an errata document.

Table 4. Evaluating Errata Document Quality

Content	Quality Criteria
Errata Revision	Configuration controlled? (with revision and dates)
Components	Impacted component(s) part numbers identified?
Die Revision	Die revision of impacted components identified?
Description	Detailed explanation of each errata item?
Projected Impact	Errata impact to user description?
Workaround	Are work-arounds identified?
Disposition	Is a disposition plan shown for each errata item? (Showing future plans die rev. fix or to just tolerate with the work-around?)
Document updates	Is the frequency of updates adequate for the maturity of the component?
Errata Timing	What is the time delay between defect discovery and an errata update?

Notification	Is there a policy of notifying users of a serious defect prior to an errata update?

Table 5. Questions for complex COTS components without errata

1.	Can all register variations and configurations be monitored and/or tested by the integrator?
2.	How does the component supplier become aware of bugs in their component? (e.g. from their tech support)
3.	How does the component supplier notify their customers of changes, fixes, and work-arounds?
4.	How does the component supplier document necessary changes to insure correct usage of component? (Tech Alerts, Tech App Note, Datasheet revision)
5.	Note that if there is no existing errata document, this will require more work by the integrator to understand the component maturity and ensure correct operation the component.

AFE 75 recommends that certification authorities and avionics system customers, e.g., Department of Defense (DoD) and platform integrators, adopt SAE EIA-4899 & IEC/TS 62239-1 standards for availability and updates of errata after they are updated.

2.9.7 References

1. European Aviation Safety Agency Certification Memorandum, CM-SWCEH-001, Development Assurance of Airborne Electronic Hardware, August , 2011

2. TechAmerica Standard, ANSI/EIA-STD-4899A-2009, "Standard for preparing an electronic components management plan," February 11, 2009.

3. International Electrotechnical Commission/Technical Specification, IEC/TS 62239-1, "Process management for avionics - Management plan - Part 1: Preparation and maintenance of an electronic components management plan," edited by International Electrotechnical Commission, Edition 1.0, July 2012)

2.9.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

ANSI	American National Standards Institute
CEH	Complex Electronic Hardware
CM	Certification Memorandum
COTS	Commercial-off-the-Shelf
DoD	Department of Defense
EASA	European Aviation Safety Agency
EIA	Energy Information Administration
IEC	International Electrotechnical Commission
MAC	Media Access Control
PCIe	Peripheral Component Interconnect Express
SAE	Society of Automotive Engineers
SD	Secure Data
sRIO	Serial Rapid I/O
STD	Standard
SW	Software
TS	Technical Specification
USB	Universal Serial Bus

2.10 Counterfeit Electronic Parts

Manufacturing technologies are increasingly advanced and standardized as globalization of all markets continues; and as a result, the opportunities and potential rewards for counterfeit items in all markets also increase. The risks associated with counterfeiting include (1) risk to life and safety for those who depend on a product that may include a counterfeit part; (2) loss of revenue and damage to the reputation of a manufacturer whose products are counterfeited; and (3) financial loss to the purchaser or user of a counterfeit part. All of these risks, and others, may be present in airborne electronic hardware (AEH), but the first one is clearly of most concern.

2.10.1 Counterfeit Parts Issue Details

Of all the items that may be counterfeited, electronic parts are among the most difficult to deal with:

- They are often difficult to detect without expensive and complex test equipment.
- They may perform adequately until certain stresses are applied at critical stages in operation.
- Their designs and production processes can change rapidly; and at least in the case of those used in AEH applications
- They are typically used in very small volumes for any given application; and they often pass through many "links" in a supply chain that is beyond the control and visibility of the AEH user.

The counterfeit issue includes purchasing, quality, and engineering aspects. The quality aspect is focused on detection and disposition of counterfeit parts. The purchasing aspect is focused on avoidance of counterfeit parts. If electronic parts are purchased from the original component manufacturer (OCM), or from an authorized distributor, the risk of receiving a counterfeit part is low; if not, the risk can be very high. The engineering aspect includes steps to analyze and mitigate risks in the application.

Often, because of obsolescence or other shortage situations, it is necessary to procure electronic parts from sources other than OCMs or authorized distributors. In such cases, it is necessary for engineering to conduct application-specific risk analyses. For applications that are critical for performance and safety, the cost to evaluate the risk and minimize the impact of a potential counterfeit part may be easier to justify than it is in less critical applications.

2.10.2 Relationship to safety and certification

Almost all AEH systems are highly integrated and technically complex:

1. They must operate successfully for long periods of time (often decades), under highly stressful conditions.
2. The consequences of failure include loss of life, risk to national security
3. They are subject to extremely high financial impact for any failure.

The electronic parts used in AEH systems include memories and logic components with billions of transistors. They are almost always designed and produced for target markets other than

AEH, and are thus not evaluated thoroughly by the manufacturer for any AEH applications. It may be possible for counterfeit parts to operate without system failure until the system is required to operate in certain ways or under certain environmental conditions; and when this occurs, the system may fail. It is therefore often difficult to determine the impact of an undetected counterfeit part in the AEH design and certification stage.

The costs to detect, analyze, and mitigate the risks of counterfeit parts can vary widely, and therefore the AEH community must have consensus on the methods, processes, and data to be used in the certification process, with respect to the risk of counterfeit electronic parts, and disposition of such parts when detected.

2.10.3 Existing activity

In recent years, the issue of counterfeit parts has been the subject of considerable attention in the commercial and military aerospace industries, and in other similar industries. The U.S. Government Accountability Office summarized the issue in its report to the Senate Armed Services Committee in 2012 [1] and the U.S. Department of Commerce published the results of a counterfeit parts assessment in 2009 [2]. The U.S. Congress has addressed counterfeit parts in its 2013 National Defense Authorization Act [3]. The European Aviation Safety Agency (EASA) has issued a Safety Information Bulletin regarding counterfeit parts [4].

Aerospace integrators, avionics manufacturers, and operators have conducted many meetings and seminars, and have published information related to counterfeit electronic parts. The standards organizations also have been active, and References [5-11] are representative of their work.

The standard that is most widely used by the AEH industries to address counterfeit parts is SAE AS5553A [8]. It is currently undergoing revision, and it is the product of a large and widely ranging list of aerospace participants. Although it addresses the quality, purchasing, and engineering aspects of the counterfeit parts issue, its emphasis is clearly on quality and purchasing, and less on engineering. Thus there may be a need for further standards work to address engineering issues.

A major task of the Aerospace Vehicle System Institute (AVSI) AFE 75 is to evaluate the large volume of information that has been generated about counterfeit electronic parts and published in a wide range of fora, and extract what is useful for safety and certification. There currently is no recognized AEH organization that is responsible for this task.

2.10.4 Technology weakness/deficiency

In a sense, there is no major technology weakness, since the counterfeit parts issue is totally a result of perfidious(not trustworthy) activities on the part of those individuals and organizations that have chosen to deceive their customers and violate laws.

In another sense, the technology weakness is our limited ability to detect counterfeit parts in all their forms and variations; and to develop countermeasures to make counterfeiting more difficult. Considerable research is being done in these areas, and progress is being made; however, the counterfeiters also continue to develop their methods, and it will always be a struggle for those who are trying to thwart them.

2.10.5 Process weakness/deficiency

The process weakness, or deficiency, is in our so-far unachieved consensus of how to conduct application-specific risk analyses for suspect counterfeit parts, and how to evaluate such analyses for the certification process.

2.10.6 Recommendation/desired outcome

Of all the industry standards referenced in this report for mitigating the effects of counterfeit electronic parts, SAE AS5553 [8] and SAE AS6462 [9] are widely used and referenced by producers and users of AEH. AFE 75 acknowledges the growing consensus for using SAE AS5553 and AS6462 the "baseline" requirement for certification with respect to counterfeit electronic parts .

AFE 75 recommends that certification authorities and avionics system customers, e.g., the Department of Defense (DoD), platform integrators, and equipment developers adopt SAE AS5553 and SAE AS6462 standards.

2.10.7 References

1. United States Government Accountability Office Report to the Committee on Armed Services, U.S. Senate, "DoD Supply Chain – Suspect Counterfeit Electronic Parts Can Be Found on Internet Purchasing Platforms," GAO-12-375, February 2012.
2. United States Department of Commerce, Bureau of Industry and Security, Office of Technology Evaluation, "Defense Industrial Base Assessment: Counterfeit Electronics," November 2009.
3. "National Defense Authorization Act for Fiscal Year 2013," 112th Congress, 2nd Session, H.R. 4310.
4. European Aviation Safety Agency Safety Information Bulletin, SIB 2011-27, "Suspect (Bogus - Counterfeit) Integrated Circuits," November 18, 2011.
5. International Electrotechnical Commission/Publically Available Specification, IEC/PAS 62668-1, "Process management for avionics – Counterfeit prevention – Part 1: Avoiding the use of counterfeit, fraudulent and recycled electronic components," Edition 1.0, May 2012.
6. TechAmerica Technical Bulletin, TB-0003, "Counterfeit Parts & Materials Risk Mitigation," February, 2009.
7. SAE International, Inc., SAE AS6174, "Counterfeit Materiel; Assuring Acquisition of Authentic and Conforming Material," May 2012.
8. SAE International, SAE AS5553A, "Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition," January 2013.
9. SAE International, SAE AS6462, "Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and DispositionVerification Criteria, November 2012.SAE International, "Fraudulent/Counterfeit Electronic Parts; Tool for Risk Assessment of Distributors," December 2011.

2.10.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AEH	Airborne Electronic Hardware
AFE	Authorization for Expenditure
AS	Aerospace Standard
AVSI	Aerospace Vehicle System Institute
DoD	Department of Defense
EASA	European Aviation Safety Agency
GAO	Government Accountability Office
H.R.	House Resolution
IEC	International Electrotechnical Commission
OCM	Original component manufacturer
PAS	Publically Available Specification
SAE	Society of Automotive Engineers
SIB	Safety Information Bulletin
TB	Technical Bulletin
U.S.	United States

2.11 Undocumented Features

2.11.1 Description of the issue

Integrated Circuit (IC) manufacturers often include circuitry in their production devices that is not intended for use by the end user [1-4]. Documentation for these circuits is rarely provided. This circuitry falls into one or more of the following categories:

(a) Manufacturing test support. As part of a Design-For-Test (DFT) methodology, these circuits provide controllability and observability of functional circuitry to improve fault detection during manufacturing test. The manufacturer and their manufacturing partners (fabrication and packaging houses) use these circuits to test newly fabricated devices. Examples include Scan and Memory Built-In-Self-Test (BIST).

(b) Debug and diagnostic support. These circuits provide controllability and observability of functional circuits to assist circuit debug. Examples include observation points and multiplexers, clock control, and function isolation.

(c) Function test support. These circuits increase the testability of the device. This category is intended to go beyond traditional features, like JTAG 1149.1 (Boundary Scan [5]), which is usually well documented. Instead this category is meant to describe advanced features like register and memory access, run control, and debug support. Documentation for these features is usually provided to eco-system (everything that exists in a particular environment) partners who provide test equipment for the device, but not to end-users. Examples include microprocessor emulators, which use extensions to Boundary Scan to provide register and cache access, breakpoint capability, and run control for microprocessors.

(d) Performance monitoring. These circuits are used to monitor functional circuit operation, count events, and optionally take some kind of action based on the results. Some manufacturers provide documentation for these circuits to end-users. Examples include event counters for L2 cache accesses and hits.

(e) Debug and test of new chip functions in real silicon. These circuits may require fabrication and test in production silicon before release to end-users.

2.11.2 Relationship to safety and certification

If an undocumented feature were to become activated, the device's functionality could be changed, degraded, or defeated. If activated during flight, aircraft safety could be affected because the equipment in which the device is used could have its availability, output data integrity, or ability to perform intended function affected.

In addition, certification could be affected because the undocumented feature diminishes the applicants' ability to understand the device and ensure the equipment in which it is used performs its intended function(s).

2.11.3 Existing activity

There is one known activity in this area. The ad-hoc "MultiCore for Avionics" (MCFA) [6] group is working to establish a process to exchange design and process related information between the aerospace and semiconductor (specifically microprocessor) industries. The intent of

this information exchange is to provide source information for the avionics companies' development and certification processes.

2.11.4 Technology weakness/deficiency

If sufficient “interlocks” (i.e. mechanisms to positively disable the undocumented features) are not provided, the undocumented features could be activated during flight. In many cases, sufficient interlocks may be present even though details about the features are not known. For example, features which are initiated through extended boundary scan commands could be disabled through appropriate control of the pins in the boundary scan interface pins. In other cases the type of interlocks are not known, and this issue needs to be addressed through a process-oriented approach.

2.11.5 Process weakness/deficiency

Process weaknesses and deficiencies include (1) insufficient access to the minimal set of semiconductor supplier information needed to analyze undocumented features, and (2) insufficient guidance to perform a quantitative analysis of undocumented features.

2.11.6 Recommendation/desired outcome

This is a business issue for the semiconductor suppliers, not a technology issue. It would be possible for the suppliers to provide documentation for all the features in a device. However, the limited usefulness of this information for most customers, proprietary nature of the information, and high support costs associated with this solution make it impractical.

Note that documentation and guidance weaknesses identified in the section above is not the complete documentation for the undocumented feature – it could be just the set needed to address the problem analytically or quantitatively. Addressing these weaknesses would help applicants develop:

(a) Strategies and techniques to minimize the probability that an undocumented feature becomes activated in flight
(b) Methods to detect errant device behavior when an undocumented feature becomes activated in flight and affects device operation
(c) Architectures and implementations which mitigate potentially errant system operation should an undocumented feature become activated in flight, and
(d) Analyses which estimate the likelihood of undocumented feature activation

AFE 75 recommends that semiconductor industry coordinated research be performed on this issue. A desired outcome is the creation of an aerospace working group which builds a framework for collaboration between device suppliers and the aerospace industry. The framework would include objectives, planning, examples, and required documentation for addressing undocumented features. This guidance may be restricted to certain classes of devices such as System on Chip (SoC) processors, multicore processors, and graphics processors.

Creation of this framework is expected to require research that elaborates the categories of undocumented features listed above. An assessment of the mechanisms used to disable the undocumented features and the effects of feature activation would also be beneficial.

In addition, the semiconductor industry could benefit from a white paper that describes the problem, explains the reasons for concern, provides design guidance to minimize the effects of the undocumented features, and a list of the minimal documentation needed by the aerospace community.

2.11.7 References

1. European Aviation Safety Agency (EASA)Certification Memorandum, CM-SWCEH-001, "Development Assurance of Airborne Electronic Hardware," August, 2011 (see section 10.3 Item f).
2. Wang, L., Stroud, C. E., and Touba, N. A., "System-on-Chip Test Architectures: Nanometer Design for Testability (Systems on Silicon)", Morgan Kaufmann, 2007.
3. Weste, N. and Harris, D., "CMOS VLSI Design: A Circuits and Systems Perspective," 4th Edition, Addison Wesley, 2011 (chapter 15).
4. Colwell, Robert P., "Pentium Chronicles: The People, Passion, and Politics Behind Intel's Landmark Chips", Wiley-IEEE, 2005 (see pp 87-89).
5. Institute of Electrical and Electronics Engineers Standard 1149.1, "Standard Test Access Port and Boundary Scan Architecture," IEEE, July, 2001.
6. MultiCore for Avionics (MCFA) group, http://onboard.thalesgroup.com/2013/successful-multi-core-for-avionics-working-group-meeting-with-authorities/, Last accessed 11/7/2013.

2.11.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

BIST	Built-In-Self-Test
CEH	Complex Electronic Hardware
CM	EASA Certification Memorandum
CMOS	Complementary-metal-oxide-semiconductor
DFT	Design For Test
EASA	European Aviation Safety Agency
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
JTAG	Joint Test Action Group
MCFA	MultiCore for Avionics
SOC	System on Chip
SW	Software
VLSI	Very Large Scale Integration

2.12 Multiple, Global Electronic Supply Chains

This issue was determined not to have technological base and was thus omitted from the comparative analyses provided in appendices B, C, and D. The project members did not believe this topic was appropriate for additional research; however, it was felt that there was benefit to maintain visibility of this issue and retain this summary in the final report.

2.12.1 Description of the issue

While it may not be accurate to characterize the aerospace, defense, and high performance (ADHP) supply chain as an issue itself, it is a reality that presents a number of issues. Some of these stem from the fact that the ADHP supply chain is in reality a blend of multiple supply chains that primarily support markets other than ADHP. Additionally, the ADHP supply chain is increasingly global and as such less subjected to control by system integrators than a supply chain focused on serving ADHP system development.

As a result of global economic forces, there are many new entrants into the electronic and aerospace supply chains. Even though the new entrants might be producing products that are compliant to existing specifications, the products may or may not have the same quality or reliability that aerospace has come to expect. Visibility into lower levels of the supply chain has disappeared. The sites and facilities used for fabrication, assembly, and test often are transferred without notification to other sites, facilities, and even companies. Unstable economic, political, infrastructures of suppliers, and natural disasters can affect availability of components.

Another feature of the global electronics supply chain is its "compartmentalization" according to the end-item markets for which components are "targeted," e.g., computers, telecommunications, consumer electronics, etc., that are expected to provide the bulk of their sales. Commercial-off-the-Shelf (COTS) components and small assembly designs, production processes, configuration control processes, and quality and reliability methods are based on the needs of these target markets. The target market customers can be confident that all of the components and sub-assemblies that they use in their products have been targeted for them. By contrast, except for niche markets like satellites, aerospace is largely underserved; and aerospace users must purchase their components from a variety of other target-marketed products, such as telecommunications, automotive, and consumer electronics. Furthermore, the drivers for these various other markets often are at variance with each other. As a result, aerospace users must accommodate a variety of design, production, and support practices.

2.12.2 Relationship to safety and certification

The aerospace, defense, and high performance (ADHP) market "culture" has disappeared. That culture included, not only the visible and documented requirements, such as specifications and drawings (quite often military standards, specifications, and handbooks), but also an understanding of the market's end-item needs, and how to meet them. In many cases, supplier products far exceeded specifications, but due to the deliberate, even ponderous processes used to update them, military standards, handbooks, and specifications did not always "keep up" with the state of the art.

Two examples illustrate this issue:

1. The conductive anodic filament (CAF) problem first emerged in the ADHP industries in the 1990s, and those industries responded vigorously with research and development work that essentially eliminated it by controlling the glass fiber materials and process used to produce printed circuit boards. As a result of globalization, new entrants into the electronic supply chain were essentially unaware of this issue, and the CAF issue has re-emerged.
2. For decades, the "standard" document used to predict reliability of ADHP equipment was MIL-HDBK-217. Due to the Department of Defense (DoD) move towards commercial standards in lieu of military documents, this handbook has not been updated for almost two decades. As a result, rapid changes in electronics have significantly diminished the applicability of this document, and there is no consensus alternative to replace it.

In general, ADHP system design, production, maintenance, support, and certification processes have not kept up with the fast pace of change in the global electronics industry, and many of the assumptions built into those processes are no longer applicable.

2.12.3 Existing activity

There is currently no coordinated activity to address this issue. There are, however, organizations that have missions, charters, etc. that could position them to deal with it. Examples are the SAE Avionics Process Management Committee, SAE G-12 Committee, and various committees and organizations within American Industries Association (AIA), SAE International, and other aerospace organizations.

2.12.4 Technology weakness/deficiency

This is not a technology issue.

2.12.5 Process weakness/deficiency

The ADHP industries do not currently have processes, or organizations, in place to address the issues associated with multiple and global supply chains. The current "system" (if it can be so described) is to address specific issues on *ad hoc* bases as they arise and cause problems to the ADHP industries. The issues associated with multiple and global supply chains will never be easy to address, and they are even more difficult if each ADHP company is left to address them on its own individual basis.

2.12.6 Recommendation/desired outcome

The ADHP industries need to have a structured, coordinated approach to (1) identify specific issues associated with multiple and global supply chains, (2) develop ADHP requirements to respond to the challenges, (3) implement the requirements in statements of work, contracts, policies, etc., and (4) verify compliance to the requirements. A coordinating organization that can represent the ADHP industries, such as AIA, is in a position to play the coordinating role.

2.12.7 References

No specific references are cited here.

2.12.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

ADHP	Aerospace, defense, and high performance
AIA	American Industries Association
CAF	Conductive Anodic Filament
COTS	Commercial-off-the-Shelf
DoD	Department of Defense
HDBK	Handbook
MIL	Military
SAE	Society of Automotive Engineers

2.13 Usage Domain Analysis

2.13.1 Description of the issue

Many Commercial-off-the-Shelf (COTS) components are tailor-made for prioritized customers, i.e., internal elements have been streamlined to fulfill other purposes than asked for in the avionics industry (e.g., for consumer or telecommunication applications). The functionality in many COTS components also exceeds what is typically required by avionics applications. Therefore, there is a need to understand how the COTS components behave for the intended application and how they can be controlled, i.e., a usage domain analysis should be performed.

In certain cases, it may also be of interest to validate the usage domain with respect to safety and system requirements.

2.13.2 Relationship to safety and certification

Incomplete or inaccurate knowledge of how a COTS component behaves for the intended application can lead to erroneous behavior or improper data processing. Erroneous behavior or improper data processing could result from incorrect settings of configuration registers, inadvertent changes of used functions or activation of unused functions, or incorrect environmental usage.

2.13.3 Existing activity

Guidance for the avionics industry already exists but is not harmonized.

RTCA/DO-254 [1] Section 11.2.1 states that certification credit for COTS components may be gained by establishing that the components have been selected on the basis of technical suitability of the intended application, such as component temperature range, power or voltage rating, or that additional testing or other means has been used to establish these.

The European Aviation Safety Agency (EASA)'s Certification Memorandum (CM) [2] expects that usage domain aspects are dealt with. For all digital COTS integrated circuits (IC)s except for simple ones, the usage domain should be determined, e.g. used functions (description, configuration characteristics, mode of operation, etc. must be documented), unused functions, the means to deactivate functions and the means to control any inadvertent activation of unused functions have to be under control. Also means to manage component resets, power on and clocking configuration, and usage conditions have to be understood.

The EASA CM also requires validating the usage domain for components having low product service experience or for components that are highly complex. For those components, use of features should be justified, validation of the usage domain through tests or analysis should be performed and the determinism of a component (required by the system) should be ensured (bus throughput, data latency, worst case execution time (WCET), stack activity, etc.) For some complex components where non-deterministic behavior is apparent (e.g. dependent complex interfaces, multiple internal buses used dynamically) additional assessment may be required (unless it is shown that the system's behavior can deal with such kind of non-deterministic behavior). Also, an assessment of all specific multi-core functionalities should be performed for multi-core processors.

In the Aerospace Vehicle System Institute (AVSI) AFE 43 project a handbook, "Handbook for the Selection and Evaluation of Microprocessors for Airborne Systems," DOT/FAA/AR-11/2 [3] was developed. This handbook (referenced as the Federal Aviation Administration (FAA)'s Handbook below) discusses several usage domain aspects. More importantly, it specifies the possible application of a "safety net" in the avionics operational environment to detect and handle failures in a non-deterministic system (or component) and addresses system architecture, flexible configurations and the monitoring process required to make the safety net approach feasible.

The handbook also discusses incorrect settings of pullup/pulldown pins, configuration registers or inadvertent changes. In addition, it describes that care must be taken to provide assurance that unused capabilities are properly disabled and deactivation of unused features has become an additional consideration.

2.13.4 Technology weakness/deficiency

This topic is not directly related to technology weaknesses or deficiencies, but the smaller the geometries become, the corresponding technologies needed to cope with these geometries become more and more prevalent. This, together with the continuously increasing on-chip complexity, makes it harder to validate the usage domain.

Moreover, existing policy and guidance do not address the subject of non-determinism related to the technical characteristics described.

2.13.5 Process weakness/deficiency

EASA's guidance in the CM and FAA's Handbook are overlapping. However, there are some topics in the handbook that have not been considered in the CM and vice versa. A brief comparison between the two documents has been performed in [4] and the activities not included in the CM are briefly discussed in the Handbook Comparison in Section 2.21 in this document.

Other sections in this document (e.g. 2.11 Undocumented Features) have identified that complete documentation for ICs are frequently not provided to the end user, thus the usage domain may not be fully determined.

Validating the usage domain for highly complex components can be an extremely large task for which insufficient information is provided by the component manufacturer to accomplish it.

2.13.6 Recommendation/desired outcome

The following suggested usage domain analysis guidance process is extracted from EASA's CM and FAA's Handbook and should be added in a new standard to be developed.

Usage Domain Analysis Guidance Process:

1. Collect data of the component to determine appropriateness of use, usage limitations and the functions associated with the component

a. Data to be collected may be specifications, data sheets, user manuals, installation manuals, application notes, service bulletins, user correspondence, and errata notices[6].

Note: Insufficient data might lead to inappropriate determination or incorrect validation of the usage domain.

2. Determine the usage domain for complex COTS components (recommended minimum determination level):
    a. used functions of the component,
    b. unused functions of the component,
    c. the means used to deactivate functions,
    d. external means to control any inadvertent activation of unused functions,
    e. external means to control any inadvertent deactivation of used functions,
    f. means to manage component resets,
    g. power-on configuration,
    h. all clock domains,
    i. usage conditions (clock frequency, power range, temperature, voltage etc.),
    j. integrated development environment suitability,
    k. correct settings of pullup/pulldown pins, and
    l. suitability against the manufacturer's published performance data.

Note: Complexity should be defined before determining the usage domain

3. Validate the usage domain with respect to safety and system requirements for new or highly complex components
    a. Use of features should be justified and be consistent with the system, hardware, software and safety requirements.
    b. The validity of the usage domain should be ensured through:
        i. test and/or analyses of used functions,
        ii. verification of support for fault tolerance (including detection and real-time repair or reconfiguration),

[6] Collected information could also be data requested from and/or purchased from the manufacturer, results from test and analyses, service history (if any), evaluation of software to be used in the devices, system functionality and requirements, operational use cases, evaluation of partition dynamics (including configuration pattern resets), dependency pairs supporting data integrity, forensic analyses, safety and system requirements modeled and refined to consider architecture and design.

iii. effectiveness of unused function deactivation and methods of detecting unused function activation,
iv. verification of errata workarounds,
v. validity of the usage conditions defined by the component manufacturer,
vi. design margin analysis,
vii. identification and analysis of previous and current usage domains,
viii. analysis of the impact of the inadvertent activation of unused functions,

c. The determinism of the component should be ensured (additional assessment may be required for complex architectures) or safety net design validated to ensure that requirements are met.
d. An assessment of all specific multi-core functionalities should be performed for multi-core processors.

Note: Newness and high complexity should be defined before validating the usage domain.

4. Use the safety net approach for areas where the determination or validation of the usage domain is insufficient or too complicated to perform.

AFE 75 recommends the applicant fulfill two objectives; 1) determine the usage domain and 2) validate the usage domain. If the applicant cannot fulfill these two objectives with their own processes, it is suggested they use the guidance in EASA's CM (Section 9.3.3) and FAA's Handbook (Section 4), see suggested guidance process above.

AFE 75 recommends a new standard. The objectives should be the main focus in a chapter addressing usage domain analysis. That is the same answer given for the leftover section, i.e. additional handbook considerations. In the long term, AFE 75 recommends the RTCA association create a new COTS guidance material to include the above issues and activities. The objectives should be the main focus in a chapter addressing usage domain analysis.

2.13.7 References

1. RTCA/DO-254 (EUROCAE ED-80), "*Design assurance guidance for airborne electronic hardware*," April 19, 2000.
2. European Aviation Safety Agency (EASA), Certification Memorandum, EASA CM – SWCEH – 001, "*Development assurance of airborne electronic hardware," Issue 01, Revision 01*, March 2012.
3. Aerospace Vehicle Systems Institute, AFE 43, "Handbook for the selection and evaluation of microprocessors for airborne systems," FAA Report DOT/FAA/AR-11/2, February 2011.

4. Forsberg, H., (Saab), “Comparison Between The Handbook for the Selection and Evaluation of Microprocessors for Airborne Systems and EASA’s Certification Memorandum SWCEH – 001”, October 2012.
5. International Electrotechnical Commission/Technical Specification, IEC/TS 62239-1, "Process management for avionics - Management plan - Part 1: Preparation and maintenance of an electronic components management plan," edited by International Electrotechnical Commission, Edition 1.0, July 2012

2.13.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AR	Aviation Research
AVSI	Aerospace Vehicle System Institute
CM	EASA Certification Memorandum
COTS	Commercial-off-the-Shelf
DO	Document
DOT	Department of Transportation
EASA	European Aviation Safety Agency
ED	EUROCAE Document
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
IC	Integrated Circuit
IEC	International Electrotechnical Commission
RTCA	Radio Technical Commission for Aeronautics
SWCEH	Software & Complex Electronic Hardware (Section in EASA)
TS	Technical Standard
WCET	Worst Case Execution Time

2.14 Production Follow-up

2.14.1 Description of the Issue

The component market is led by consumer electronics. One of the key drivers of this market is the cost decrease of more expensive highly reliable products. Passive components represent 80% of the components used on electronic circuit boards today.

Manufacturers tend to reduce efforts in research and development, investment and process controls at production lines for low cost electronics. These efforts are normally done on production lines for high reliability products.

The passive component industry is composed of a large number of small manufacturers merged into companies which are major players in the field. This makes achieving effectiveness of investment and Research & Development (R&D) even more difficult.

In recent years, the passive component market turnover and volume has risen sharply. See European Passive Component Industry Association (EPCIA) source [1]). This has a potential consequence of losing effective control of production quality. In fact the strong growth needs total control at all levels of companies and manufacturers.

Low Cost Components

Another factor is the cost of passive components which is very low compared to the high value-added of an active component one which generates high added value.

In the world of active components, the major suppliers invest considerable budgets in major R&D projects, in production lines for high yield to achieve a high quality production. Some products are used in applications characterized by a high availability (24 hours per day, 7 days a week), and for other products customer satisfaction is the major criterion.

Reliability and failures analysis

Recent studies addressing accelerated life testing in vibration and temperature showed that passive components compatible with Restriction of Hazardous Substances (RoHS) are less reliable than active ones after lead-free soldering processes. Refer to the lead-free section 2.8 for additional information.

One of the root causes is that (in some cases) necessary modifications mandatory for RoHS soldering temperature compatibility have not been correctly done (e.g., higher soldering temperature than with SnPb alloy).

Other studies launched by U.S. or European labs show that a lot of equipment failures are due to passive components.

2.14.2 Relationship to safety and certification

All these parameters (RoHS, high production volume, quick increase, low value and/or low cost components) could contribute to low reliability/quality of passive components.

Reliability handbooks are taking into account component reliability and performances generally based on feedback or models and due to low frequency of updates may not be able to take into account variations in production lines and reliability drifts through time.

Designers have to establish safety margins at design levels based on reliability figures provided by data bases (such as MIL HDBK 217 [2] or FIDES [3]) and their knowledge of component market.

Today, capacitors seem to be the main cause of failures. Evaluation of returns due to passive component failures show that bad soldering (caused by wettability issues due to contamination of soldering finishes), cracks in components (due to thermal-mechanical constraints) and internal delamination are the main root causes.

2.14.3 Existing activity

Major aerospace companies are conducting studies on component reliability which demonstrate that passive components are contributors to relative poor reliability at equipment or subassembly levels.

Meetings and workshops between Equipment and component manufacturers are being organized in the U.S. and Europe through the following professional associations and unions.

- CALCE (Center for Advanced Life Cycle Engineering (University of Maryland, College Park)) [4]
- ANADEF (ANAlyse de DEFaillance French Association working on electronic component failure analysis) [5]
- EDFAS (Electronic Device Failure Analysis Society) [6]
- ISTFA (International Symposium for Testing and Failure Analysis) [7]
- EPCIA (European Passive Component Industry Association) [1]

2.14.4 Technology Weakness/deficiency

There are few evolutions or innovations in the passive component domain. For example:

- Numerous ceramic or metallic packages are still in use with a high thermal expansion coefficient difference with solder and printed circuit board (PCB).

- Customer pressure to reduce cost does not encourage innovation.
- RoHS changes have not always been taken into account in the materials used for passive components.
- Component manufacturer technology assessment tests are, in some cases, not adequate or adapted to harsh avionics environments

2.14.5 Process weakness/deficiency

In several cases, passive component industry uses small manufacturing units.
These small units present some issues like manual operations or lack of rigorous process control.

Another weakness is linked to internationalization; a same component reference can come from different countries or production lines.

Sometimes deficiencies can originate from lack of investments, or insufficient qualification batches at the component manufacturer's level.

2.14.6 Recommendations/desired outcome

AFE 75 recommends aviation systems suppliers use IEC 62239-1[8] at equipment level to define component selection and criteria for use of passive components in manufacturing (production follow up).

AFE 75 recommends General Aviation Manufacturer Association (GAMA) [9] or AeroSpace and Defense Industries Association of Europe (ASD) [10] develop common procedures to help component manufacturers to assess their products. A way to achieve this should be to involve Equipment supplier Industry associations like GAMA or ASD and then open discussions with component manufacturer representatives in order to apply these recommendations based on aeronautic field requirements resulting in a methodologies leading to product improvements and costs acceptable to both parties.

Win-win solutions should be found with minimum impact on COTS passive components including increase of quality, reproducibility, and justifiable costs.

AFE 75 recommends that avionics system customers, e.g., platform integrators, and equipment developers adopt IEC 62239-1 standards after initial production has started.

2.14.7 References

1. European Electronic Component Manufacturers Industry Association, EPCIA, http://acronyms.thefreedictionary.com/European+Electronic+Component+Manufacturers+Association, Last accessed 11/03/2013

2. MIL HDBK 217 F Military Handbook, Reliability Prediction of Electronic Equipment notice 2 (28 July 1995)

3. FIDES: A Methodology for Components Reliability, http://fides-reliability.org/, Last accessed 11/03/2013

4. Center for Advanced Life Cycle Engineering, CALCE (Maryland University), http://www.calce.umd.edu/general/center/consortium.htm, Last accessed 10/27/2013

5. ANADEF, (ANAlyse de DEFaillance French Association working on electronic component failure analysis), http://www.anadef.org/lanadef.html, Last accessed 10/27/2013

6. Electronic Device Failure Analysis Society, EDFAS, http://edfas.asminternational.org/portal/site/edfas/MyEDFAS/Home/, Last accessed 10/27/2013

7. International Symposium for Testing and Failure Analysis, ISTFA, http://www.asminternational.org/content/Events/istfa/, Last accessed 10/27/2013

8. IEC 62239-1 Process management for avionics - Management plan - Part 1: Preparation and maintenance of an electronic components management plan, edited by International Electrotechnical Commission (July 2012)

9. General Aviation Manufacturer Association (GAMA), http://www.ask.com/wiki/General_Aviation_Manufacturers_Association, Last Accessed 11/03/2013

10. AeroSpace and Defense Industries Association of Europe (ASD), http://www.asd-europe.org/, Last accessed 11/03/2013

11. UTE-80811-Edition A: Fides Methodology Guide (January 2011)

2.14.8 Acronyms and abbreviations

The following acronyms and abbreviations are used in this section:

ANADEF	ANAlyse de DEFaillance , French Association specializing in failure analysis
ASD	AeroSpace and Defense Industries Association of Europe
CALCE	Center for Advance Life Cycle Engineering (Univ. of Maryland)
COTS	Commercial-off-the-Shelf
EDFAS	Electronic Device Failure Analysis Society
EPC	European Passive Component

EPCIA	European Passive Component Industry Association
FIDES	Latin Root of the French word "*Fiabilité*", reliability in English.
GAMA	General Aviation Manufacturer Association
HDBK	Handbook
IEC	International Electrotechnical Commission
ISTFSA	International Symposium for Testing and Failure Analysis
MIL	Military
Pb	Lead
PCB	Printed Circuit Board,
R&D	Research & Development
RoHS	Restriction of Hazardous Substances
Sn	Tin
Sn/Pb	Tin/Lead
US	United States
UTE	French Standard

2.15 Intellectual Property (IP)

2.15.1 Description of the issue

For integrating an intellectual property (IP) core in a DO-254 [1] compliant design, the IP user needs to establish whether the IP has been managed, designed and verified with the same level of rigor as an implementation (e.g. the Programmable Logic Device (PLD)), developed to comply with DO-254, or needs additional data and/or re-generated data through additional activities, in order to meet the objectives of DO-254.

As airborne electronic hardware becomes more complex and technology evolves, experience is gained in the application and use of the procedures described in DO-254. Therefore it is important to fully consider the certification aspects when adopting the relatively new techniques of IP usage and System on Chip (SoC) design architectures for an airborne application.

2.15.2 Relationship to safety and certification

Digital and Mixed Signal (IP, integrated circuits, Application Specific Standard Product (ASSP), Application Specific Integrated Circuit (ASIC), Field Programmable Gate Array (FPGA) and PLD components), which have functions that can affect the safety of the aircraft, are heavily used in electronic equipment. It has become necessary to ensure that potential design errors are taken into account and the design and maintenance processes (including configuration management) are mastered.

Because of the nature and complexity of systems containing digital logic, adherence to a structured design approach may be used to show compliance to certification objectives.

The most common means of showing such compliance for complex PLDs is adherence to the guidelines of RTCA document DO-254/ED-80, “Design Assurance Guidance for Airborne Electronic Hardware”.

The design process is modulated by a safety classification and complexity of the design.

The DO-254 document addresses IP as Commercial-off-the-Shelf (COTS). General considerations about COTS are included in § (section) 11.2 as follows:

> “*COTS components are used extensively in hardware designs and typically the COTS components design data is not available for review. The certification process does not specifically address individual components, modules, or subassemblies, as these are covered as part of the specific aircraft function being certified. As such, the use of COTS components will be verified through the overall design process, including the supporting processes, as defined in this document. The use of an electronic component management process, in conjunction with the design process, provides the basis for COTS components usage.*”

2.15.3 Existing activity

There is currently no coordinated activity to address this issue. However, there are a number of groups dealing with IP and SoC. IP and SoC have been in the commercial electronics market for more than 10 years. It is worth mentioning the following activities and initiatives:

- Spirit Consortium [2], now Accellera Systems Initiative [3]; Accellera Systems Initiative www.accellera.org. Accellera was founded in 2000 from the merger of Open Verilog International [4] and VHSIC Hardware Description Language (VHDL) International [5]. In June 2009 a merger was announced of Accellera and another major EDA organization, Structure for Packaging, Integrating and Re-using IP within Tool-flows (SPIRIT) Consortium, a standards organization focused on developing standards for IP deployment and reuse. In December 2011 Accellera and Open SystemC Initiative (OSCI) [6] approved their merger adopting the name Accellera Systems Initiative.
- Design & Reuse (D&R) [7], http://www.design-reuse.com.

FAA Order 8110.105 Chg 1 [8], sections 2.8 (g) and 4.9. And specifically for the aerospace world, in Europe:

- SoC from Civilian to Armament Re-use (SoCCER) project [9] completed in 2005 but with a lot of concepts which are still valid.
- The DO-254 User Group document "Use of Intellectual Property (IP) Cores in Airborne Electronic Hardware" [10] completed on 25th May 2011.
- European Aviation Safety Agency (EASA) Certification Memorandum (CM), EASA CM – SWCEH – 001, "Development assurance of airborne electronic hardware," Issue 01, Revision 01, March 2012 [11], sections 1.4, 4.6 (7), 8.4.2.1, 8.4.4 and 9.2 (final line).

What cannot be denied is that the IP is the way to go when handling complexity, moreover, if it is to be handled safely. Just to give hypothetical comparison, imagine software (SW) developers having to write today's complex SW applications from scratch and in assembly language, once and again, without taking advantage of reusing the myriads of available SW COTS modules.

2.15.4 Technology weakness/deficiency

There are difficulties handling the complexity and integrating IPs in a component.

2.15.5 Process weakness/deficiency

There is a lack of sufficient certification requirements. Reference [8] section 4.9 and reference [11] guidance of IP cores in its section 8.4.4 provide a starting point but the industry considers them insufficient and there is confusion on what is to be done for the certification of the IP.

2.15.6 Recommendation/desired outcome

AFE 75 recommends that when there is functionality (commonly termed as hard IP) integrated into silicon as purchased, that portion of the silicon should be treated as a COTS component. AFE 75 has determined that the IP subject is beyond the scope of this AFE 75, but it will be recommended for further research.

2.15.7 References

1. RTCA/DO-254 (EUROCAE ED-80), “Design assurance guidance for airborne electronic hardware” April 19, 2000.
2. SPIRIT Consortium, Structure for Packaging, Integrating and Re-using IP within Tool-flows, integrated in Accellera [3] in June 2009.
3. Accellera Systems Initiative, independent, not-for profit organization dedicated to create, support, promote, and advance system-level design, modeling, and verification standards for use by the worldwide electronics industry; www.accellera.org (accessed on 25/10/2013). Accellera [3] was founded in 2000 from the merger of Open Verilog International [4] and VHDL International [5].
4. Open Verilog International, integrated in Accellera [3] in 2000.
5. VHDL International, integrated in Accellera [3], in 2000.
6. Open SystemC Initiative (OSCI), integrated in Accellera [3] in December 2011. The Open SystemC Initiative (OSCI) used to be a collaborative effort to support and advance SystemC as a de facto standard for system-level design. SystemC is an interoperable, C++ SoC/IP modeling platform for fast system-level design and verification.
7. Design & Reuse (D&R) [7], http://www.design-reuse.com. Web portal for disseminating value-added information on electronic virtual components, specifically IP (intellectual property), SoC’s (systems-on-chips) and also providing enterprise-level IP management platforms. At present D&R manages 12,000 IP Cores from 400 Vendors.
8. Federal Aviation Administration (FAA), FAA Order 8110.105 Chg 1, SIMPLE AND COMPLEX ELECTRONIC HARDWARE APPROVAL GUIDANCE, 23rd September 2008.
9. SoCCER, SoC from Civilian to Armament Re-use. Project born from the idea of European leading industries in defence and aerospace and excellence academia and design houses with common interest for using Intellectual Property in Systems-on-Chip. Completed by 2005.
10. RTCA/DO-254 Users Group Position Paper DO254-UG-002 “Use of Intellectual Property (IP) Cores in Airborne Electronic Hardware” (Rev 1, 25th May 2011).
11. EASA Certification Memorandum, EASA CM – SWCEH – 001, “Development assurance of airborne electronic hardware,” Issue 01, Revision 01, March 2012.

2.15.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AFE	Authorization for Expenditure
ASIC	Application Specific Integrated Circuit
ASSP	Application Specific Standard Product
CEH	Complex Electronic Hardware
CM	EASA Certification Memorandum

COTS	Commercial-Off-The-Shelf
D&R	Design & Reuse
DO	Document
EASA	European Aviation Safety Agency
ED	EUROCAE Document
EDA	Electronic Design Automation
FAA	Federal Aviation Administration
FPGA	Field Programmable Gate Array
IP	Intellectual Property
OSCI	Open SystemC Initiative
PLD	Programmable Logic Device
RTCA	Radio Technical Commission for Aeronautics
SoC	System on Chip
SoCCER	SoC from Civilian to Armament Re-use
SPIRIT	Structure for Packaging, Integrating and Re-using IP within Tool-flows
SW	Software
UG	User's Guide
VHDL	VHSIC Hardware Description Language
VHSIC	Very High Speed Integrated Circuit

2.16 Unknown Changes

2.16.1 Description of the issue

Traditional understanding has been that, once a Commercial-off-the-Shelf (COTS) component was qualified for production, its design, production, quality and reliability assurance processes would remain stable throughout its lifetime. This is not the case in the modern electronics industry. Electronic component manufacturers routinely change designs, materials, production processes, and even performance of their components. If a COTS component has a major change, then the avionics supplier must be notified so that they can understand the impact of the change to their system. This section will define what a major change to a COTS component is, and it will establish an approach for notification.

2.16.2 Relationship to safety and certification

If a major change is made to a COTS part without the notification to the user of the part (e.g. the avionics supplier), then this part could impact the correct operation of safety-critical hardware (either in production-test or in flight).

2.16.3 Existing activity

There is a Joint Electron Devices Engineering Council (JEDEC) Standard, JESD46D [1] that states component manufacturers are required to notify their customers of any major change to a component. This standard establishes procedures to notify customers of these changes to electronic components and their associated processes. It provides a general definition of a major change to an electronic component as any change that affects the form, fit, and function of a component, or degrades the quality or reliability of a component. It also provides a suggested detailed definition of a major change in the Annex A section of the document. It contains both a time limit for the notification to customers (Product Change Notice (PCN)), and a time limit for the customer's response back to the COTS supplier. It also defines the minimum content of the PCN. Several avionics suppliers are already referencing/using this standard as part of their Electronic Component Management Plan (ECMP). (Note that an avionics supplier's ECMP is based on the objectives documented in IEC/TS 62239-1 [2].)

2.16.4 Technology weakness/deficiency

This topic does not have a technology weakness or deficiency.

2.16.5 Process weakness/deficiency

Annex A of the JESD46D specification contains a suggested detailed definition for what should be considered a major change to a component. Since it is only a suggestion, COTS component suppliers are not required to abide by this definition.

COTS assemblies (such as a Secure Data (SD) Card) may not be covered by JESD46D. The reason a major change to a component may slip through is because the manufacturer/supplier of the COTS assembly may not have imposed JESD46D as a requirement with their own COTS component suppliers. The avionics supplier would be unaware of these changes. For example, a major change to a flash component that is used inside an SD Card purchased by an avionics supplier may go unnoticed until it fails in test or in flight. This potential deficiency is covered in the COTS Assemblies section of this document.

Avionics suppliers and manufacturers still need to provide resources and processes that support and respond to PCNs from their COTS components suppliers. This includes monitoring for PCNs and their resulting internal notification to key product groups. It also includes evaluation, qualification, and analysis of these changes.

2.16.6 Recommendations/desired outcome

AFE 75 believes avionics supplier's ECMP should require their COTS component suppliers to adhere to JESD46D. Their ECMP should, as a minimum, make the detailed definition of a major change shown in JESD46D section Annex A required.

AFE 75 believes that avionics suppliers need to provide resources and processes that support and respond to PCNs from their COTS components suppliers. This should be covered in their ECMP and should include monitoring for PCNs and their resulting internal notification to key product groups. It should also include the requirement of evaluation, qualification, and analysis of these changes.

The aerospace industry would benefit from improved exchange of data between the semiconductor and aerospace industry to accomplish these recommendations.

2.16.7 References

1. Joint Electronic Device(s) Engineering Council, Solid State Technology Association, JESD46D (Customer Notification of Product/Process Changes by Solid-State Suppliers)

2. International Electrotechnical Commission/Technical Specification, IEC/TS 62239-1, "Process management for avionics - Management plan - Part 1: Preparation and maintenance of an electronic components management plan," edited by International Electrotechnical Commission, Edition 1.0, July 2012

2.16.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

COTS	Commercial-off-the-Shelf
ECMP	Electronic Component Management Plan
IEC	International Electrotechnical Commission

JEDEC	Joint Electron Devices Engineering Council
JESD	JEDEC Standard
PCN	Product Change Notice
SD	Secure Data
TS	Technical Specification

2.17 Embedded Controllers

2.17.1 Description of the issue

Controllers and sequencers are often embedded into integrated circuits to implement complex hardware functions. These controllers fetch and execute code like other processors, however the code is often fetched from internal read-only memory (ROM) or Flash, the programs are relatively small, the code or "sequence" is often written by the commercial-off-the-shelf (COTS) integrated circuit (IC) supplier, and the code is generally not modifiable by the end user.

Figure 4 shows a spectrum of devices containing embedded processors, controllers, or sequencers. Note that this issue is focusing on the controllers embedded within these devices (e.g. the controller implementing wear-leveling, error correcting code (ECC) and bad block management within an Embedded MultiMedia Card (eMMC) device), not the external controllers interfacing with an eMMC device (e.g. a system on chip (SoC) microprocessor containing an "eMMC controller"). The spectrum in the figure ranges from "Microprocessor (uP)" to "Logic", which are used to provide context and described as follows:

- "uP": those devices which clearly host avionics applications, and whose verification activities are well known, such as DO-178B/C [1] target-based testing
- "Logic": those devices which clearly implement hardware functionality, and whose development activities would typically performed using the guidance of DO-254 [2] if done by an applicant

The examples shown along the spectrum are a small sampling of real-world devices. Other device exist which, if added to the figure, would fill in the spectrum much more completely.

The concerns with embedded controllers are multifaceted. Among them:

- With the rich spectrum of devices available and on the horizon, it is often not clear how to treat a given device. Specifically, the applicability of DO-178B/C, DO-254, and/or other COTS guidance may not be clear.

- Often the existence of the embedded controller is not known by the end user or discovered late in the product life-cycle.

- It may not be feasible to perform traditional avionics development assurance steps for the system in which the device is to be used. For example, if a disk drive is to be used which contains embedded controller code (which may be proprietary to the supplier), the DO-178B/C verification artifacts may not be available and the code may not be available to the applicant.

2.17.2 Relationship to safety and certification

Existing guidance (and the guidance forthcoming from other issues described in this document) is sufficient for many COTS devices containing embedded controllers. For example, the use of a cyclic redundancy code (CRC) may be a sufficient data integrity check for eMMC device data.

With additional clarification, existing guidance could cover many more devices. However, even with additional clarification, there will be cases of devices containing embedded controllers have

inadequate development assurance. Since the code for the controllers is often written by the integrated circuit supplier, software development issues need to be considered such as verification rigor, change management, and configuration control.

Specific concerns relating embedded controllers to certification include:

- Embedded controller implementation details are usually not described in IC supplier documentation. Information such as soft error detection, error response capabilities, and configuration modes are not available to the applicant.

- Embedded controller operation and results are usually not monitored as would typically be done a microprocessor.

- The code executed by embedded controllers, or the tool used to generate the code, is usually written by COTS IC suppliers. Thus the code is not developed per DO-178B/C (so verification artifacts are not available), or the tool used to generate the code is not qualified. The source code executed by embedded controllers is not available to applicants (since it is proprietary), or the binary code generated by the tool is not verifiable.

2.17.3 Existing activity

No existing activities exist for this issue.

2.17.4 Technology weakness/deficiency

This issue does not have a technology weakness or deficiency.

2.17.5 Process weakness/deficiency

Development assurance for many embedded controllers cannot be done using DO-178B/C or DO-254 processes.

2.17.6 Recommendation/desired outcome

AFE 75 recommends that semiconductor industry coordinated research be performed on this issue. The results of the research would include defining categories of embedded controllers based on their characteristics, identifying methods to categorize a given device into an appropriate category, and creating development assurance processes for category. Possible categorization could be done along criteria such as:

1. Controller Function: Is the controller dedicated to a particular hardware function or is it capable of control general purpose outputs and buses?

2. Controller Complexity: Is the controller a simple sequencer, an arithmetic logic unit (ALU), or reconfigurable hardware?

3. Controller Instruction Storage: Is the controller instructions (or sequences) held in internal or external memory?

4. Controller Instruction Availability: Is the controller source code available to or generated by the end user?

5. Controller Instruction Type: Is the controller source code available in a High Level Language, a sequence, parameters entered into a tool, etc.?

6. Controller Instruction Modifiability: Is the controller instructions (or sequences) modifiable by the end user?

Once a particular part has been classified, that classification could be stored in a database which is maintained by the certification agencies or a related organization. Subsequent applicants could access the classification of a given device, and a change management process would be used to change a classification.

AFE 75 also recommends the generation and distribution of a white paper which describes this issue, along with recommended practices and direction, for the semiconductor industry.

2.17.7 References

1. RTCA, DO-178B, "Software Considerations in Airborne Systems and Equipment Certification, December 1, 1992, " DO-178C, 01/05/2012.
2. RTCA/DO-254, "Design Assurance Guidance for Airborne Electronic Hardware," April 19, 2000.

2.17.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AFE	Authorization for Expenditure
ALU	Arithmetic Logic Unit
COTS	Commercial-off-the-Shelf
CRC	Cyclic Redundancy Code
ECC	Error Correcting Code
eMMC	Embedded MultiMedia Card
FPGA	Field Programmable Gate Array

IC	Integrated Circuit
NAND	Not-AND, a type of Flash Memory
ROM	Read-Only Memory
RTCA	Radio Technical Commission for Aeronautics
SoC	System On Chip
uP	Microprocessor

2.18 Technology and Component Maturity

This subject was identified in AFE 75 Task but was considered to be embedded in the other issues and was not viewed to be a topic or an issue. Therefore, no research effort was expended during Task 1 or Task 2 and will not be carried forward to Task 3. The purpose of this entry is solely for showing completeness.

2.19 Component Packaging and Mounting Reliability

2.19.1 Description of the issue

Increasing component transistor counts and area reduction pressures have pushed Commercial-off-the-shelf (COTS) integrated circuit suppliers to utilize new packaging techniques such as higher pin counts, new package styles, new materials and new manufacturing processes. Of particular concern with these new packaging techniques is how they affect the components long term solder joint reliability. Long term reliability issues will generally not be caught during standard DO-160 [1] qualification testing, therefore additional criteria must be enforced to ensure new package types have been adequately characterized for use in their target environments to assure their safe operation for the life of the product.

2.19.2 Relationship to safety and certification

Packaging and mounting technologies, materials and assembly processes which have proven historical data, result in solder joint reliability predictions that exceed the expected life of the equipment and therefore are not a factor in the equipment failure rates. Unproven package types or mounting technologies that do not have historical data to ensure their solder joint reliability, may exceed the life expectancy of the equipment. Recent industry experience with these newer technologies has shown that they have significantly lower solder joint life expectancy than legacy products. If these new package types and mounting technologies are used without first determining the solder joint reliability and factoring that into the architecture of the design and/or manufacturing processes, the failure rate calculations for the equipment will be invalid resulting in unknown failures and failure rates. Typically, these types of components are utilized for the larger, more complex components that provide control and/or monitoring types of functions.

2.19.3 Existing activity

The Institute for Interconnecting and Packaging Electronic Circuits (IPC) [2] has published two standards which provide guidelines for design (IPC-D-279) [3] and reliability testing (IPC-SM-785) [4] of surface mount (SM) technology components. Reliability prediction is often done with the aid of MIL-HDBK-217 [5]. Accelerated testing for solder joint reliability usually includes the use of the Arrhenius equation to derive the “acceleration factor” between life-cycle testing and real-world temperature cycles [6]. It has been recognized that these standards are dated, and in need of updates and enhancements, but they currently provide some valid guidance that reduces the risk of introducing immature products into safety critical applications until more up to date guidance has been created.

2.19.4 Technology weakness/deficiency

Many plastics exist with a coefficient of thermal expansion (CTE) which matches that of a standard FR-4 printed circuit board (PCB) (which is about 14ppm/degree C). However, matching the CTE of the component and PCB is not always possible. There are cases when plastic packaging is not suited for an application, such as high power components which use ceramic packages for power dissipation purposes.

"Under fill" can be used to bond the component to the printed circuit board (PCB) to reduce the stress on the solder joints. There are several types of under fill materials in use with differing properties relative to workability and thermal transfer. Use of under fill may affect manufacturing test flow and equipment repair processes.

2.19.5 Process weakness/deficiency

The (IPC) guidelines (IPC-D-279 and IPC-SM-785) give users two options for assessing solder joint reliability:

1) Compare test data against pre-determined mission profiles.

2) Calculate the probability of solder joint crack failures at component end-of-life, and assume it is less than the probability of component random failures at end-of-life.

Unfortunately, data necessary to perform either assessment option is frequently not available and extensive testing may be needed to gather the data. The tests are composed of accelerated temperature tests using a special version of the package which enables continuity detection at each pin or some other test setup which can do so.

2.19.6 Recommendation/desired outcome

Applicants need guidance for a process that addresses component packaging and mounting reliability. Guidance would include objectives, planning, examples, and required documentation.

We recommend in the short term, the program electronic component management plan (ECMP) should require that a plan be developed for addressing the mounting of surface mount technology (SMT) components based on the existing guidance provided in the IPC Guidelines and MIL-HDBK-217 and require applicants to include solder joint failures in equipment fault trees when it is warranted.

We recommend for the long term, revisions to the current IPC guidelines and MIL-HDBK-217 need to be performed to incorporate new information and address technology advances. Recommended updates to MIL-HDBK-217 are discussed in section 2.7, Outdated Reliability Assessment Methods, of this document. Updates to the IPC documents are recommended to address gaps for many avionics components that are unable to fully utilize the information presented in the IPC documents for assessing durability for reasons such as:

- Many components have mission profiles that do not fit into the pre-defined mission profile use categories identified in the IPC,
- Many components have significantly longer service life requirements than identified in the pre-defined mission profile use categories in the IPC,
- Many components have significantly larger delta temperatures than identified in the pre-defined mission profile use categories in the IPC

We recommend that the referenced IPC documents be updated to include data and guidance for the identified mission profiles as well as other relevant avionics mission profiles. In addition is recommended that a method to extrapolate from documented data to other mission profiles that may not be documented be provided.

2.19.7 References

1. RTCA, DO-160, “Environmental Conditions and Test Procedures for Airborne Equipment”, December 8, 2010
2. Institute for Interconnecting and Packaging Electronic Circuits (IPC), https://acc.dau.mil/CommunityBrowser.aspx?id=22385&lang=en-US, Last Accessed 11/04/2013
3. Institute for Interconnecting and Packaging Electronic Circuits, IPC-D-279, “Design Guidelines for Reliable Surface Mount Technology Printed Wiring Board Assemblies”, July, 1996
4. Institute for Interconnecting and Packaging Electronic Circuits, IPC-SM-785, “Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments”, November, 1992
5. Military Handbook (MIL-HDBK-217F) Notice 2, “Reliability Prediction of Electronic Equipment”, February 28, 1995
6. Siewiorek and Swarz, "Reliable Computer Systems Design and Evaluation", 3rd Edition, AK Peters, 1998

2.19.8 Acronyms and abbreviations

The following acronyms and abbreviations are used in this section:

C	Centigrade
COTS	Commercial-off-the-Shelf
CTE	Coefficient of Thermal Expansion
DO	Document

ECMP	Electronic Component Management Plan
FR-4	Grade designation assigned to glass-reinforced items
HDBK	Handbook
IPC	Association Connecting Electronics Industries
MIL	Military
PCB	Printed Circuit Board
ppm	parts per million
RTCA	Radio Technical Commission for Aeronautics
SM	Surface Mount
SMT	Surface Mount Technology

2.20 Device Uprating

2.20.1 Description of the issue

The use of commercial-off-the-shelf (COTS) devices for safety-critical applications may require uprating of the device. The avionics guideline IEC62239 [1] in its § 5.1 “using components outside the manufacturer’s specified temperature range” refers to IEC 62240 [2] to specifically manage uprating. There are additional concerns with uprating of modern COTS devices, for instance faster wear-out as the technology shrinks.

A typical temperature range for devices in airborne electronic hardware (AEH) has been -40°C (-55°C at times) to +125°C; but most COTS devices are targeted for temperature ranges of -40°C to +85°C, 0°C to +85°C, or even less.

2.20.2 Relationship to safety and certification

Uprating is discouraged but it is necessary at times for the devices to undergo more extreme conditions than those stated in data sheets. If uprating is performed without control, that can lead to unpredictable behavior of the uprated device, which can be progressively or suddenly degraded, potentially failing in an unknown mode, subtly (inadvertently) or dramatically.

AEH designers who have been forced to use COTS devices outside of the data sheet ranges have made use of various techniques collectively known as “uprating” to confirm that the devices are fit for the intended purpose. As stated above, the concern with uprating is that the device was most likely to have originally been developed with design rules governing for example, the maximum current density, at a defined maximum temperature to achieve a reliability goal that is acceptable for the target market and this is not typically that of AEH.

To justify the use of a device outside of its data sheet range, detailed information is needed about that device. Control of the uprating practice has typically been left to the individual AEH designer, although there is one industry standard that purports to control the process ([2]). There is however no aerospace consensus on how, or whether, the techniques detailed in the standard should be used in AEH designs, or how to assess the resulting design implementation in the certification process ([3]).

Uprating increases the semiconductor device’s scaling-related internal stress. If the internal stress increases, the likelihood of the device time dependent wear-out and failure in long life applications also increases. For safety-critical avionics, uprating decreases the design margins and thus decreases the probability that the device functions properly during unexpected conditions.

To properly uprate complex Commercial-off-the-Shelf (COTS) devices requires detailed knowledge of their internal design and the associated manufacturing process. Unfortunately this level of detail is frequently unavailable for COTS products.

In aircraft engine applications complex COTS devices typically work at temperatures above 100°C. Full Authority Digital Engine Control (FADEC) units, for example, operate outside the margin of COTS device temperature ratings, with no options to do otherwise.

IEC TR 62240 “Use of semiconductor devices outside manufacturers’ specified temperature range” ([2]) is the standard for addressing the topic and is referenced by the IEC TS 62239 “Preparation of an electronic components management plan” ([1]).

Uprating solutions are considered exceptions, when no reasonable alternatives are available, under other or ’normal’ conditions devices are to be utilized only within the manufacturer’s specifications (IEC/TS62239-1 [1] Electronic Components Management Plan (ECMP) statement).

2.20.3 Existing activity

There is currently no coordinated activity to address this issue.

IEC TR 62240 [2] is used directly or as a starting point by main avionics suppliers.

Very few after-market test houses have the required hardware implementation to perform parts uprating and even fewer can reproduce the original part manufacturer’s methodology.

Complex devices can be damaged by the application of inappropriate configuration fields, voltage or current stresses. Any third party attempting to test other foundry devices must have intimate knowledge of their architecture, circuit implementation, and design methodology. Without this expertise it is practically impossible to write efficient test code (without the device vendor test vectors and all the vendor’s knowledge about the device and the silicon process).

Another practice is to test and certify commercial products outside the manufacturer's maximum ratings. This practice is extremely dangerous. Electronic devices should, in principle, not be used outside of their published design ratings. Any such use will void any associated manufacturer’s warranty.

2.20.4 Technology weakness/deficiency

Typical wear-out mechanisms in semiconductors are gate-oxide wear-out, electromigration and hot-carrier injection. These mechanisms can, to some extent, be accelerated by uprating.

These and other wear-out mechanisms can be non-progressive and hence non predictable in time or in failure mode.

Some unshrinkable parameters prevent the power supply voltage from proportionally scaling with the physical devices. Therefore, the process of technology scaling impacts the noise and voltage uprating for each new generation of COTS in a non-linear fashion.

2.20.5 Process weakness/deficiency

The aerospace, defense, and high performance (ADHP) industries do not currently have processes, or organizations, in place to address the issues associated with uprating.

Uprating guidelines exist: IEC TR 62240 “Use of semiconductor devices outside manufacturers’ specified temperature range” [2] is the standard for addressing the topic, referenced in the IEC TS 62239 “Preparation of an electronic components management plan” [1]. IEC TR 62240 [2] is considered to be a very complete and correct document.

A lot of avionics manufacturers do some type of uprating, they do not all use the IEC TR 62240 [2] document or they use it as a starting point or a reference only.

There are ongoing efforts to tackle the topic at the physics level (reliability) but when it comes to on-chip complex designs, not much guidance exists within open literature.

2.20.6 Recommendation/desired outcome

The uprating of modern electronic devices is often overlooked and treated lightly in many cases in the industry. There are companies that just put the chips on the boards/equipment and undertake qualification tests and, if no errors are detected, they consider the design, uprated devices included, qualified, without taking into account any manufacturing variations.

AFE 75's recommendations for a future document regarding COTS devices Assurance Methods for certification are:

- To use IEC TR 62240 [2] as the basis for uprating.
- To develop a common format for reporting the results of each instance of uprating. For each device that is uprated in a given application, an "Uprating Report" should be generated. The report will show how each provision of IEC TR 62240 [2] has been addressed in the specific instance. The format could be standardized in the form of a blank form and published within an annex of IEC TR 62240 [2].

The main points identified within IEC TR 62240 [2] are summarized here below:

For device capability, one of the following strategies should be followed:

1. Device parameter re-characterization
2. Stress management. See whether $T_{junction}$ is the only device temperature to respect, according to the datasheet or contact the manufacturer to find out, or also $T_{ambient} + T_{case}$
3. Parameter conformance assessment + Higher assembly level testing

For device reliability, see mainly clause 5.2.3. The clause 5.2.3 "Device reliability assurance" of IEC TR 62240 [2] considers this: "... qualify electrical performance of the devices over the intended range of operating and environmental conditions after a reliability stress conditioning exposure that reflects the life cycle of the application; and determine a margin, supported by analysis using adequate data from the intended application, between the maximum normal operating junction temperature and the absolute maximum rated junction temperature.". I.e. do not forget to cycle the device thermally to the expected equivalent life:

- Temperature Acceleration Factor AFT, according to Arrhenius equation
- Voltage Acceleration Factor AFV
- Overall Acceleration Factor AFO = AFV × AFT

And then:

- Continuous device quality assurance

AFE 75's position is that uprating should be avoided if possible, but if it can't be avoided, it should be done following the guidance given in IEC/TR 62240:2005 Process management for avionics [2]. The guidance is in a process step format; it does not include "shalls," but a manufacturer can be required to follow the steps therein.

A lot of avionics manufacturers do implement some type of device uprating in a minimum number of cases, but they may or may not make use the IEC TR 62240 [2] document. It should be noted that, as with all such documents, IEC TR 62240 [2] has to be updated continuously to stay in touch with the electronics industry.

To get this IEC TR 62240 [2] into the direct path for all certifications it should be mentioned as exiting guidance on the topic in the next design assurance guidance for AEH.

2.20.7 References

1. IEC/TS 62239-1, Technical Specification, Process management for avionics – Management plan – Part 1: Preparation and maintenance of an electronic components management plan, Edition 1, 2012-07
2. International Electrotechnical Commission/Technical Report, IEC/TR 62240, "Process management for avionics - Use of semiconductor devices outside manufacturers' specified temperature range," Edition 1.0,
3. Biddle, S. Richard, "Reliability implications of derating high-complexity microcircuits," COTS Journal, Vol. 2, No. 2 February 2001.
4. National Aeronautics and Space Administration/Technical Publication, NASA/TP—2003–212242, May 2003 EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating. Last update: April 2008, Incorporated Addendum 1
5. RNC-CNES-Q-60-522, Issue 1, 14/04/2003 - Transformation of the environmental constraints into components requirements (obsolete but very interesting)
6. ECSS-Q-ST-30-11C Rev 1, 4 October 2011, Space product assurance, Derating - EEE components

2.20.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section.

ADHP	Aerospace, Defense, and High Performance
AEH	Airborne Electronic Hardware
AFE	Authority for Expenditure
AFO	Overall Acceleration Factor
AFT	Temperature Acceleration Factor
AFV	Voltage Acceleration Factor
C	Centigrade
COTS	Commercial-Off-The-Shelf
CNES	Centre national d'études spatiales (National Centre for Space Studies)

ECSS	European Cooperation for Space Standardization
ECMP	Electronic Components Management Plan
EEE	Electrical, electronic, and electromechanical (parts used in space systems)
FADEC	Full Authority Digital Engine Control
IEC	International Electrotechnical Commission
INST	Instructions
NASA	National Aeronautics and Space Administration
Q	Quality (of the ECSS Space Product Assurance Branch)
RNC	Referential Normatif du CNES
ST	Standard
$T_{ambient}$	Ambient Temperature
T_{case}	Maximum (outer case) temperature a component can stand
$T_{junction}$	Junction Temperature
TP	Technical Publication
TR	Technical Report
TS	Technical Specification

2.21 Additional Handbook Considerations

2.21.1 Description of the issue

During the Aerospace Vehicle Systems Institute (AVSI) AFE 75 work, Section 9 in European Aviation Safety Agency (EASA)'s Certification Memorandum (CM) [1] was taken into account. The activities in the EASA CM were looked at and the potential issues behind them were identified. Finally, these identified issues were matched with the issues listed in this project. If they were not covered and considered to be in line with this project they were added either as new topics or as part of other topics, or in some cases, if they were considered too small and did not fit into any other topic, taken care of in this section.

Then, to make sure that previous work in the AVSI AFE 43 project and specifically the guidance in the Handbook for the selection and evaluation of microprocessors for airborne systems [2] were covered, the Handbook was compared with EASA's CM. It was considered for those identified subjects in the Handbook that were covered in the EASA CM (or for those subjects covered in the EASA CM but not in the Handbook) that they were already taken care of. Hence, the subjects that were left and unconsidered were those identified in the Handbook but not by the CM.

These missing subjects were related to visibility and debug, simulated computer environment, and safety net monitors. See Reference [3] for identified specific suggestions covered by the Handbook and not by EASA's CM. Specifically, the identified suggestions covered by the Handbook and not by the EASA CM were:

- System developers should work closely with the integrated circuit component manufacturer when setting up the development environment.
- Applicants should be aware of the integrated development environment's suitability with respect to their specific project requirements.
- Care should be taken if hardware performance monitors will be used to provide insight into the internal operation of a microprocessor.
- The limitations of industry benchmarks to fully exercise microprocessor behavior should be understood and augmented with other tests and or analyses.
- The differences between the simulated computer environment and target computer should be documented by the system developer as part of the test environment.
- The timing and cycle accuracy of the simulated target computer should be assessed.
- Safety-net monitors should be used, to detect and handle failures that cannot be thoroughly evaluated through test and evaluation methodologies (e.g., non-deterministic behavior). System architecture should be designed to allow the safety nets to handle detected failures in the aircraft operational environment.

Comparing the Handbook with EASA's CM was not straight forward. The Handbook addresses the selection and evaluation of microprocessors without specific activities identified while the Certification Memorandum gives guidance for all types of digital Commercial-Off-The-Shelf

(COTS) integrated circuits (ICs) and identifies up to 16 explicit activities to be performed. These activities are also dependent on design assurance level and specific component service experience.

The following list shows EASA's 16 activities in Section 9 in the EASA CM and how we have taken care of these in this project.

1. COTS classification – This is not an issue and has not been taken care of in this report. In EASA's CM, COTS classification is used to help the applicant to classify COTS components into different complexity classes and then to perform different amount of activities for each component given the corresponding class to which it has been assigned.
2. Identification and storage of component data – This activity has been taken care of in Section 2.9 *Availability and updates of errata* and Section 2.13 *Usage domain analysis*.
3. Design data/manufacturer control – This activity is expected to ensure the applicant that the manufacturer has a documented quality management process, deterministic and repeatable manufacturing process and has an internal component approval process. This activity is taken care of in this section.
4. Usage domain determination – This activity has been taken care of in Section 2.13 *Usage domain analysis*.
5. Usage domain validation - This activity has been taken care of in Section 2.13 *Usage domain analysis*.
6. Evidence of component manufacturer errata sheets – This activity has been taken care of in Section 2.9 *Availability and updates of errata*
7. Assessment of errata sheets - This activity has been taken care of in Section 2.9 *Availability and updates of errata*
8. Documentation of past experience and experience during development – This activity is taken care of in this section.
9. Manufacturer configuration management – This activity is taken care of in Section 2.16 *Unknown changes.*
10. Change impact analysis - This activity is taken care of in Section 2.16 *Unknown changes.*
11. Validation and verification (V&V) against the requirements of the component – No issue explicitly addresses this topic. To extract design requirements from component metadata such as data sheets etc. and then perform verification against these requirements (which often shows up as derived on both the software and hardware side) is considered common practice. Datasheet information that is considered implementation is not typically converted to requirements. Verification against the requirements of the component is therefore not further described in this report. However, to validate these requirements may not be common practice. This activity is therefore taken care of in this Section.
12. Includes three different sub tasks; a) Analysis at component level to refine the failure modes, b) performance assessment and functional safety assessment take into account the used configuration of the component, and c) insurance that the programmed configuration that is used (configuration via hardware and software pin-programming) actually

configures the component as expected - It is considered that b) and c) are implicitly taken care of in Section 2.13 *Usage domain analysis*. Sub task a) however is taken care of in this section.

13. COTS service experience – This is not an issue and has not been taken care of in this report. In EASA's CM, COTS service experience is used to help the applicant to classify COTS components into low or sufficient product service experience and then to perform different amount of activities for each component given its product service experience.
14. Stability and maturity of the component – Section 2.18 *Technology and component maturity* refers to other sections in this document. This activity is considered to be covered in Section 2.9 *Availability and updates of errata.*
15. Architectural mitigation should be implemented for components that could cause catastrophic events – This activity is not considered as an issue. It is assumed to be covered by the requirements of no common mode failures in catastrophic events and the related common mode analysis which is part of the safety assessment and that has to be performed.
16. Robust partitioning (where hardware mechanisms are used to implement partitioning) – This activity is taken care of in this section.

2.21.2 Relationship to safety and certification

Use of safety-net monitors is indeed related to safety. The safety-net methodology presumes the monitored component(s) will misbehave during its/their service life. The responsibility for defining and using safety net monitors belongs to the integrator developing the application-specific architecture.

All suggestions in the bulleted list (not the numbered list) above are derived from the Federal Aviation Administration (FAA) Handbook and relate to safety and certification in one way or another.

2.21.3 Existing activity

Guidance for the avionics industry already exists in EASA's CM, the FAA Handbook and the other AVSI AFE 43 research reports [4-8].

2.21.4 Technology weakness/deficiency

Some highly integrated, complex components can be very difficult, if not impossible, to test or analyze completely either in development and integration, or in service in the operational environment. The safety net concept was intended to handle failures in the operational environment by a combination of architecture design and failure detection and handling in the operational environment.

2.21.5 Process weakness/deficiency

The FAA Handbook and the other AVSI AFE 43 research reports describe the subjects related to visibility and debug, simulated computer environment, and safety net monitors. However, since the Handbook and AFE 43 reports do not constitute accepted formal guidance by either the FAA or EASA, work will be required to establish guidance in those areas.

2.21.6 Recommendation/desired outcome

Since this section takes care of several different leftover suggestions and activities from both the FAA Handbook and EASA's CM, the certification recommendations have been grouped together to address the two different origins separately.

Four of the seven identified suggestions in the FAA Handbook as described above can be grouped together since they all address tools supporting the integration of the COTS component. To address the adequacy of tools and tool suites supporting this integration Research & Development (R&D) is suggested. R&D should establish the technical baselines (modeled and implemented) for escalating systems complexity and meet the needs of component manufacturing, aerospace development, regulatory certification, and aircraft/air traffic control (ATC) maintenance.

If any tool is used to support the integration of a COTS component it is proposed at this time (without accomplished R&D) that the following activities are performed:

- A short description should be written to explain how system/hardware developers will work with the integrated circuit component manufacturer when setting up the development environment, including any information sharing with intellectual property protection between the above parties or third party tool vendors.
- The applicant should briefly describe the integrated development environment's suitability with respect to their specific project requirements.
- If a simulated component environment is used to simulate a COTS component's behavior and this tool is used for formal verification of requirements;
    - The differences between the simulated component environment and the component itself should be documented by the system/hardware developer as part of the test environment.
    - The timing and cycle accuracy of the simulated target component should be assessed.

Of the three remaining suggestions at least two of them can be written as activities to be performed. The suggested certification recommendation for these two is therefore:

- If any on-chip hardware performance monitor will be used to provide insight into the internal operation of a component, this should be carefully documented, including any limitations with respect to the specific project requirements.
- Industry benchmarks cannot be used alone to exercise the behavior of a microprocessor. If industry benchmarks are used to exercise any behavior of a microprocessor, this should be documented and coordinated with the certification authorities to assure its appropriateness.

For the last one from the handbook, safety-net monitors, this one have been suggested to be used in the guidance recommendations of the COTS usage domain, see Section 2.13. However, the concept of safety-net monitors will be hard to write general certification recommendations for since the nets must be based on the unique architecture, design, and behavior (including Human Machine Interface (HMI)) of each application.

The general recommendation for those implementing safety-net monitors is therefore to read and understand the guidance written in the FAA Handbook [2], and then apply it to the unique aspects of each application, i.e.:

- Safety-net monitors should be used, to detect and handle failures that cannot be thoroughly evaluated through test and evaluation methodologies (e.g., non-deterministic behavior, inadequate HMI, operational problems, error and fault detection, consistency checking, automated safety analysis, degradation measurement during maintenance, support during technical refreshment, Etc.). System architecture should be designed to allow the safety nets to handle detected failures in the aircraft operational environment. The safety nets and supporting tools, technologies, and information sharing mechanisms should be designed to support component manufacturing, aerospace development, regulatory certification, and aircraft/ATC maintenance.

Note: Safety net monitors can also be developed as part of the system design and be used for additional purposes (e.g., monitoring the developing system design, HMI resulting in a system that monitors and prioritizes the system/human interface during development, during certification, during operation, and during maintenance).

In EASA's CM, five activities were considered as issues that should be taken care of in this section. The certification recommendation for these activities is to directly use the CM, i.e.:

- When the design data for a new (with low service experience) complex[7] component is not available for review, the applicant should ensure that the manufacturer has a documented quality management process, deterministic and repeatable manufacturing process and has an internal component approval process.
- For new complex components, past experience (if any) and experience during development should be documented.
- Validation against the requirements of the component should be performed for all complex components. Documents from the manufacturer should be used when the requirements are validated.
- Failure modes and failure rates of all components should be assessed in a failure modes and effect analysis (FMEA). The FMEA also includes effects and detection mechanisms. If a new complex component is used where all failure modes might not be known or detectable, worst case effect with respect to usage of the component must be assumed. Operational safety nets may then be used to detect and handle these worst case effects.
- When a COTS component is used in an implementation that requires robust partitioning, a partitioning analysis (including spatial and temporal assessments) should be performed

[7] The difference in complexity of digital COTS ICs ranges from extremely simple logic gates such as AND and NAND up to very complex multicore microcontrollers. The certification aspects associated with those components may therefore differ. Adopting a standardized classification method for digital COTS ICs will aid the applicant/equipment supplier to identify the design assurance strategies required by the applicable certification basis. EASA describes one way to classify digital COTS ICs into three different complexity classes; *simple*, *complex* or *highly complex*.

to show that the COTS component can provide robust partitioning. If robust partitioning is not confirmed by the partitioning analysis, a means of mitigation external to the COTS component may need to be implemented. For example, a periodic reset of configuration controls to each partitioned software to establish a pattern of component configuration.

In the long term, it is advised for the Radio Technical Commission for Aeronautics (RTCA) association to create a new COTS guidance material to include the above issues and activities. Depending on the outcome of the suggested R&D for tools supporting the integration of COTS components, it might be a possible to update IEC/TS 62239 [9] with a new section addressing these tools.

2.21.7 References

1. European Aviation Safety Agency Certification Memorandum, CM – SWCEH – 001, Development assurance of airborne electronic hardware, Issue 01, Revision 01, March 2012.
2. Aerospace Vehicle Systems Institute, AFE 43, "Handbook for the selection and evaluation of microprocessors for airborne systems," FAA, DOT/FAA/AR-11/2, February 2011.
3. Forsberg H., Saab, "Comparison Between The Handbook for the Selection and Evaluation of Microprocessors for Airborne Systems and EASA's Certification Memorandum SWCEH – 001", October 2012.
4. Aerospace Vehicle Systems Institute AFE 43 Phase 1 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-06/34, Dec 2006.
5. Aerospace Vehicle Systems Institute AFE 43 Phase 2 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-08/14, June 2008.
6. Aerospace Vehicle Systems Institute AFE 43 Phase 3 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-08/55, Feb 2009.
7. Aerospace Vehicle Systems Institute AFE 43 Phase 4 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-10/21, Sept 2010.
8. Aerospace Vehicle Systems Institute AFE 43 Phase 5 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-11/5, May 2011.
9. International Electrotechnical Commission/Technical Specification, IEC/TS 62239-1, "Process management for avionics – Management plan – Part 1: Preparation and maintenance of an electronic components management plan," edited by International Electrotechnical Commission, Edition 1.0, July 2012.

2.21.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AFE	Authorization for Expenditure
AFE 43	Selection and Evaluation of Microprocessors and SoC R&D Project
AND	AND Logic Form
AR	Aviation Research
ATC	Air Traffic Control
AVSI	Aerospace Vehicle Systems Institute
CEH	Complex Electronic Hardware
CM	EASA Certification Memorandum
COTS	Commercial-Off-The-Shelf
DOT	Department of Transportation
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FMEA	Failure Modes and Effect Analysis
HMI	Human Machine Interface
IC	Integrated Circuit
IEC	International Electrotechnical Commission
NAND	Not AND, i.e. negation of Logical “AND”
R&D	Research & Development
RTCA	Radio Technical Commission for Aeronautics
SW	Software
SWCEH	Software & Complex Electronic Hardware (Section in EASA)
TS	Technical Specification
V&V	Verification and Validation

2.22 Obsolescence Management

2.22.1 Description of the issue

Obsolescence, also called Diminishing Manufacturing Sources (DMS), or Diminishing Manufacturing Sources and Material Shortages (DMSMS), has been a fact of life for all products since manufacturing began. It has, however, been especially vexing for the airborne electronic hardware (AEH) industry since the decade of the 1990s, when most manufacturers of electronic components, sub-assemblies, and equipment exited the military and aerospace markets to concentrate on larger and more lucrative markets such as computers, telecommunications, consumer electronics, etc. With the exceptions of the virtual machine environment (VME) card industry and very small niches such as space, there are essentially no suppliers of electronic components and sub-assemblies devoted to military and aerospace customers. A major outcome of this situation is obsolescence as a major concern for avionics manufacturers, operators and maintainers.

Avionics products typically are intended to operate successfully, in defined configurations, for several decades; in contrast to products for other markets, where the design and operating lifetimes are often less than five years. Furthermore, designs and configurations of electronic products targeted for other markets evolve continuously throughout their lifetimes, in response to technological progress and relentless customer demands for better performance and lower cost.

In its most extreme form, obsolescence occurs when a given product no longer is available because the manufacturer abruptly discontinues production, and no substitute is available. This rarely happens for electronic components and sub-assemblies, because they are superceded by similar products with slightly different features or specifications. These changes may be recognized by the manufacturer as having potential impact on the user, and a new part number is issued. If the product is targeted for a large market, the manufacturer may perform extensive testing and analysis to evaluate the product's performance in the intended application. With few exceptions, this is not done for AEH applications.

Because of the way our electronic supply chains and markets are structured, it has become the responsibility of the AEH users of electronic components, sub-assemblies, and equipment, to manage and mitigate the risks of those products in their own applications. The methods and processes used to address obsolescence can vary widely, and there is a need to assure that the associated costs and efforts to do so are agreed upon, to assure a "level playing field" among the various aerospace participants. The certification process is a good place to provide this assurance.

This issue may share some traits with other issues described in this report, e.g., counterfeit electronic parts, undocumented features, and undocumented changes (Section 2.10).

2.22.2 Relationship to safety and certification

As early as 1996, the impact of obsolescence was recognized as having a significant impact on avionics certificaion, when a report to the administrator of the Federal Aviation Administration (FAA) stated that systems employing commercial electronic components *"will be in a continuous state of recertification throughout the life cycle"* [1]. To this date, there has been no aerospace industry consensus on how to recognize and evaluate the efforts of avionics producers

to account for obsolescence in system design, operation, and support throughout the aircraft life cycle in the continuing airworthiness process, and within the replacement of obsolete components in the technical refresh processes.

2.22.3 Existing activity

Throughout the past two decades, the aerospace industry has devoted considerable effort, activity, and resources to address the issue of component obsolescence. The U.S. Department of Defense (DoD) has conducted an annual DMSMS Conference, and an Aging Aircraft Conference for many years, and has published a DMSMS Guidebook [2]. In Europe, the Component Obsolescence Group has conducted an annual conference to address and mitigate the effects of obsolescence, and has published a number of guidebooks. Most U.S. DoD programs require a program-specific DMSMS Plan as a deliverable.

A number of obsolescence prediction and life-cycle management software tools have been developed, and are in use by aerospace manufacturers to aid them in anticipating and responding to obsolescence issues.

Many organizations have emerged over the years to acquire inventories of remaining electronic parts as they are made obsolete by their manufacturers, and then to make them available for sale to customers who need them to continue manufacturing or to support existing products into which they have been designed. Some such organizations also have acquired intellectual property (IP) for obsolete parts, and have the capability to manufacture limited volumes of otherwise obsolete parts.

Most of the AEH responses have been program-, product-, or application-specific. The majority of presentations at the various obsolescence conferences have been *ad hoc* descriptions of how a given program or aerospace manufacturer has identified and addressed a specific obsolescence risk. Typical responses include last-time buys of parts inventories, obtaining parts from after-market suppliers, and system re-design.

Two aerospace industry documents have been published to address obsolescence at the organizational level, rather than as application-specific; both of them include requirements for a corporate level obsolescence management plan, that can then be applied to specific products, programs, or applications. IEC TS 62239-1 [3] describes requirements for an obsolescence management plan, including (1) organizational structure and interfaces, (2) subcontractor DMSMS management, (3) sustainment DMSMS strategy, (4) design concepts to minimize DMSMS risk and impact, (5) DMSMS monitoring and surveillance, (6) resolving DMSMS issues, and (7) DMSMS risk assessment. TechAmerica GEIA-STD-0016 [4] is receiving widespread acceptance in the aerospace industry.

2.22.4 Technology weakness/deficiency

The major technology activity with respect to obsolescence is the development of software tools for predicting obsolesence, and for managing the life cycle of products with respect to obsolescence. To the extent that those tools are less than perfect, this is a technology weakness.

Another potential technology weakness is the inability to evaluate the performance of "successor" products in aerospace applications, as electronic parts become obsolete. This is not a problem for "target market" users, i.e., the major customers for whom the products are designed, because the evaluation is conducted by the part manufacturer.

2.22.5 Process weakness/deficiency

There currently is no AEH industry consensus on an approach to dealing with obsolescence; typical responses to obsolescence are application-specific, and not applicable to more than individual occurrences of obsolescence. This is both a technical issue (performance and reliability), and a financial one (cost to deal with obsolescence).

IEC TS 62239-1 and TechAmerica GEIA-STD-0016 are directed at an organizational approach to obsolescence, and contain requirements for organizations to prepare obsolescence management plans applicable to all obsolescence issues encountered by the organization.

2.22.6 Recommendations/desired outcome

IEC TS 62239-1 and TechAmerica GEIA-STD-0016 should be viewed as aerospace industry consensus documents for preparing organizational level obsolescence management plans, and such plans should be the basis for evaluating applications with regard to obsolescence management. Although no standard can ever be considered "final," these documents are usable in their current revisions. They will be revised as necessary in the future.

AFE 75 recommends that the requirement to address obsolescence management through TechAmerica GEIA-STD-0016 be incorporated into the system design and certification processes through a higher-level document.

2.22.7 References

1. "Report of the Challenge 2000 Subcommittee of the FAA Research, Engineering, and Development Advisory Committee to the Administrator of the FAA," March 6, 1996.
2. "Diminishing Manufacturing Sources and Material Shortages," Defense Standardization Program Office, August 2012.
3. IEC TS 62239-1, International Electrotechnical Commission, edition 1.0,"Process management for avionics – Management Plan – Part 1: Preparation and maintenance of an electronic components management plan," July 2012.
4. TechAmerica GEIA-STD-0016, "Standard for Preparing a DMSMS Management Plan," August 2011.

2.22.8 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this section:

AEH	Airborne Electronic Hardware
DMS	Diminishing Manufacturing Sources
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoD	Department of Defense
FAA	Federal Aviation Administration
GEIA	Government Electronics and Information Technology Association
IEC	International Electrotechnical Commission

IP	Intellectual Property
STD	Standard
TS	Technical Specification
U.S.	United States
VME	Virtual Machine Environment

2.23 Acceptable Level of Compliance Evidence

This subject was identified at the beginning of the AFE 75 Project and was considered to be an outcome of the research during Task 1 discussions and was not viewed to be a topic or an issue. Therefore, no research effort was expended during Task 1 or Task 2 and will not be carried forward to Task 3. The purpose of this entry is solely for showing completeness.

2.24 Multiple Supply Chains

This subject was combined with "Globalization of the Electronic Supply Chains" in the AFE 75 COTS AEH Task 2 and is documented in section 2.12.

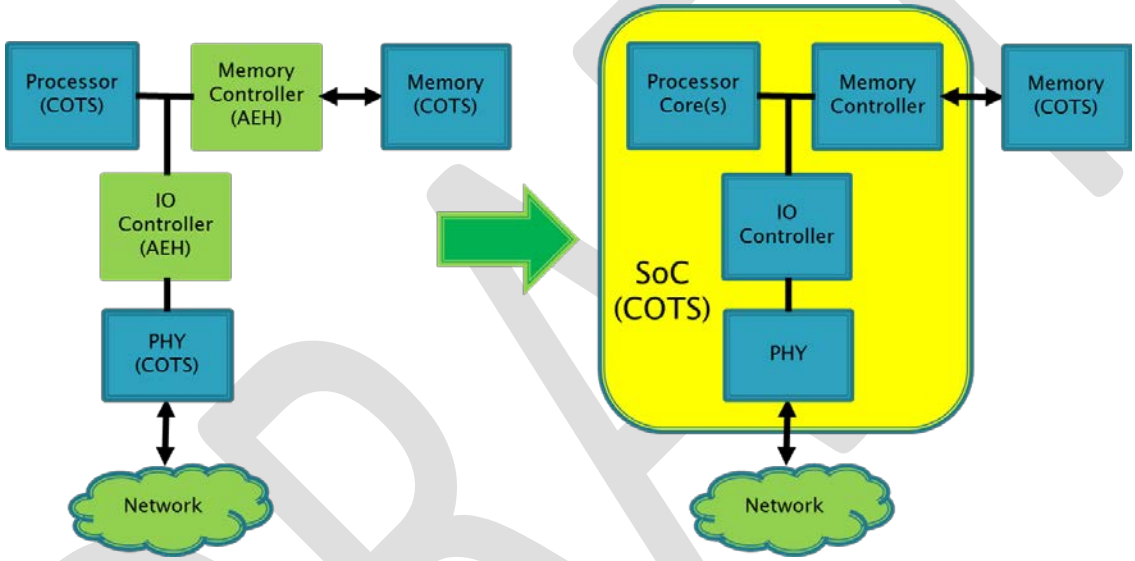
2.25 Demonstration Methods for Safe Use of Complex COTS in AEH

This subject was identified at the beginning of the AFE 75 Project and was considered to be an outcome of the research during Task 1 discussions and was not viewed to be a topic or an issue. Therefore, no research effort was expended during Task 1 or Task 2 and will not be carried forward to Task 3. The purpose of this entry is solely for showing completeness.

2.26 System On Chip Devices

2.26.1 Description of the issue

The needs for higher performance, smaller circuits, and lower cost have motivated Integrated Circuit (IC) suppliers to create highly integrated devices commonly referred to as a System on a Chip (SoC). SoCs are ubiquitous in modern commercial-off-the-shelf (COTS) electronic equipment. A typical example of an SoC would be a device which contains one or more computing cores, one or more memory controllers, and several peripheral functions all connected by a bus or interconnect fabric. Figure 5 depicts a computer system composed of traditional devices and an equivalent SoC-based system.



These devices bring remarkable advantages to electronic equipment. For avionics, however, they also present design assurance challenges such as:

(a) Logic circuits traditionally designed by applicants are now designed by semiconductor suppliers. Examples include memory controllers, core interconnection, and peripherals [1]. The semiconductor suppliers, in general, don't follow design assurance guidance for airborne electronic hardware such as DO-254 [2]. If an unstructured or low-rigor process is used to develop the IC, excessive design errors may be present in production silicon. Many of the issues described in other sections of this document address this concern.

(b) High levels of integration have dramatically reduced observability of the integrated circuits [3]. This tends to hinder the ability of the applicant to verify various aspects of the device and the ability to monitor it during flight.

(c) Highly integrated devices may be non-deterministic which can disrupt testing and analysis. The Handbook for the Selection and Evaluation of Microprocessors for Airborne Systems [4] defined safety nets as a method of a more robust method to detect

device and system failures and anomalies and recover operational ability to ensure continuous safe flight and landing. This may also reduce the growing difficulties and costs of design assurance for highly integrated, complex, non-deterministic airborne electronic hardware (AEH) and software within aircraft systems and reduce the labor burden for Federal Aviation Administration (FAA) regulation compliance and design assurance.

Since an SoC may implement a substantial portion of a system, there exists a broader concern that architectural decisions are also made by the suppliers of COTS SoCs. This means that higher-level aspects of the system (integration of functionality, allocation of communication channels and bandwidth between portions, power distribution nets, etc.) which uses the COTS SoC are determined by the SoC supplier. For example, the determinism of a computing system could be highly influenced by the architectural choices made by the COTS SoC supplier.

2.26.2 Relationship to safety and certification

Insufficient development assurance for a COTS SoC could lead to design errors in fundamental devices of safety-critical systems. Problems such as reduced availability, loss of function, misleading information, common-mode faults, or inability to continue safe flight and landing could result.

In addition, certification could be affected if a supplier's development processes diminish the applicants' ability to properly understand and use the device. This, in turn, reduces the ability to ensure the equipment in which it is used performs its intended function.

A highly integrated, complex device that exhibits non-deterministic behavior can be extremely difficult to completely assure system design and be exhaustively tested and/or analyzed. The safety net approach is an alternative way to mitigate the risks associated with COTS SoCs via both passive and active methods designed into aircraft systems. If it is not feasible to show that complex aircraft systems are sufficiently free of anomalous behavior by evaluating system devices, the safety net alternative can mitigate unforeseen or undesirable COTS operation by detecting and recovering from anomalous behavior at the operational system level. This approach requires the safety net be designed as a function within the aircraft system. The safety net can include passive monitoring functions, active fault avoidance functions, and control functions for recovery of system operations. System architecture and control and recovery functions should be designed to facilitate effective system recovery from anomalous events.

Certification of systems using COTS SoCs is complicated by the potential lack of design artifacts for the SoC and the reduced ability to monitor and control SoC functions.

2.26.3 Existing activity

The European Aviation Safety Agency (EASA) Certification Memorandum (CM)-SWCEH-001) [1], EASA research project EASA.2008/1 [5], and AFE 43-developed Handbook for the Selection and Evaluation of Microprocessors for Airborne Systems [3] all address this issue in varying degrees. EASA CM-SWCEH-001 addresses many aspects of COTS SoCs. Upcoming documents from both EASA (Multicore Certification Review Item (CRI)) and FAA (Multicore Issue Paper and Policy Statements) are expected to address multicore devices in more detail.

2.26.4 Technology weakness/deficiency

Limited observability and controllability of SoC devices inhibit the ability to monitor and debug these devices. These limitations affect the ability to perform design assurance for systems containing non-deterministic devices and also inhibit complexity management in systems that use SoC devices.

2.26.5 Process weakness/deficiency

As evidenced by their success in bringing reliable devices to market, most COTS SoC suppliers competently design and verify their products. However, these suppliers rarely follow the structured development processes described in DO-254. A process for aerospace companies to obtain COTS SoC supplier design and verification information for use as source information in certification activities is not well accepted or established.

2.26.6 Recommendation/desired outcome

AFE 75 recommends that further basic level research involving semiconductor industry collaboration be performed on this issue. One desired outcome is the creation of an aerospace working group which builds a framework for collaboration between COTS SoC suppliers and the aerospace industry. This group would:

- Establish processes for COTS SoC suppliers to efficiently, securely disclose source information to aerospace customers.
- Establish recommended lists for “disclosed” and “assessed” data from IC suppliers to aerospace industry. Disclosed data would be securely disclosed to aerospace customers; assessed data would be assessed one time and the assessment results would be made part of the disclosed data.
- Create guidance for the COTS SoC industry which describe development practices (e.g. structured processes, requirements-driven development) and design practices (e.g. undocumented feature interlocks) that would be of benefit to applicants.
- Share process and guidance information with the silicon industry.

Safety nets could show that systems are sufficiently impervious to anomalous behavior by ensuring continuous functional availability and reliability, satisfying applicable regulations, and meeting airworthiness requirements. However, research and development should be performed to determine methods and standards to support modified design assurance and certification requirements for the safety net approach.

2.26.7 References

1. "Development Assurance of Airborne Electronic Hardware", EASA CM-SWCEH-001, March 2012
2. "Design Assurance Guidance for Airborne Electronic Hardware", DO-254/ED-80, RTCA/EUROCAE, April 19, 2000
3. Wang, Stroud and Touba, "System-on-Chip Test Architectures: Nanometer Design for Testability (Systems on Silicon)," Morgan Kaufmann, 2007
4. Aerospace Vehicle Systems Institute, AFE 43, "Handbook for the selection and evaluation of microprocessors for airborne systems," FAA, DOT/FAA/AR-11/2, February 2011.
5. European Aviation Safety Agency Research Project, EASA.2008/1,"Safety Implications of the use of System-On-Chip (SoC) on Commercial-Off-The-Shelf (COTS) Devices in Airborne Critical Applications", 2008

2.26.8 Acronyms and Abbreviations

AEH	Airborne Electronic Hardware (DO-254 Developed ASICs and FPGAs)
AFE	Authorization for Expenditure
AFE 43	Selection and Evaluation of Microprocessors for Critical Airborne Systems
AR	Aviation Research
ASIC	Application-Specific Integrated Circuit
CEH	Complex Electronic Hardware
CM	EASA Certification Memorandum
COTS	Commercial-off-the-Shelf
CRI	Certification Review Item
DO	Document
DOT	Department of Transportation
EASA	European Aviation Safety Agency
ED	EUROCAE Document
EUROCAE	European Organisation for Civil Aviation Equipment

FAA	Federal Aviation Administration
FPGA	Field-programmable Gate Array
IC	Integrated Circuit
IO	Input Output
PHY	Physical Layer
RTCA	Radio Technical Commission for Aeronautics
SoC	System on Chip
SW	Software

3. AFE 75 Results and Conclusions

This AFE 75 report, based on global industry and regulatory expert experience, shows the tip of the COTS AEH issues iceberg (known issues), and provides information and methods for COTS AEH solution development including:

1. use of existing standards and guidance documents as a structure for future evolution of COTS Standards,
2. future COTS standards to implement this structure,
3. use of the Aerospace Vehicle Systems Institute as a mechanism for combined industry/regulatory/manufacturing research and development of COTS issues related to the development of COTS standards and guidance,
4. mechanisms to shortcut the slow evolution of standards,
5. a candidate vision of the eventual COTS standards linked to evolving development assurance standards, and
6. identification of standard bodies responsible for the implementation of the ongoing COTS solution(s).

All organizations and individuals who work with COTS AEH in avionics should read and understand this report, and those who address these COTS AEH issues should use AFE 75 research results to work current and future COTS AEH issues.

Although both the commercial and military segments of the aerospace market are increasingly dependent on COTS, there is no aerospace consensus on methods to assure their safety and airworthiness in AEH, or on criteria to verify that those methods are used properly in design, production, or support. A major characteristic of the COTS electronics market is the rapidity with which it changes, and the regular emergence of new issues that can affect avionics safety and airworthiness. The COTS issues identified in this report are seen as a baseline set of issues. They may be modified as needed and additional issues may be added in the future. AFE 75 explains how the issues can impact safety and airworthiness of aircraft, and how they can be addressed in the certification process. To the extent possible, existing industry handbooks, standards, reports, and technical publications are leveraged in recommended document structure, and in future work beyond the scope of AFE 75. Where additional knowledge is required, research to produce that knowledge and the candidate responsible organizations are identified.

This report provides a common structured approach for industry use to evaluate COTS AEH issues. It is applied to issues addressed in this report and is recommended for application to future issues not addressed herein. The approach is presented in a manner that supports development of project-level COTS AEH mitigations that can be rolled into development design assurance and a practical compliance solution to FAA Engineers and delegates and to Standards administrators. This report provides a stand-alone treatment of each issue (Section 2), a five-step suggested evolution of COTS and development assurance standards and guidelines (Appendix B), and a comparison of the 21 technological issues (Appendix C).

The structured approach provides:

1. details technical information about each issue,
2. specifies research required to provide new knowledge needed to implement solutions for the issues,
3. explores required tools, standards and guidance needed for COTS-based systems development assurance, certification, and maintenance, and
4. considers certification and assessment criteria and methods for the given issues.

This structured approach can be used to evaluate and work emerging COTS AEH issues. System/aircraft development projects will be required to deal with COTS AEH issues. Some of these COTS issues will be beyond the resources of a single project or a single development organization. AFE 75 demonstrates that the Aerospace Vehicle Systems Institute (AVSI) is a viable research environment to enable multiple industry and regulatory partners to address those COTS issue too large, complex, and unresolved to be addressed by single projects or single organizations. Aerospace management must become aware of the serious nature and scope of COTS AEH issues and support the communal research necessary to avoid project roadblocks, achieve required safety, and avoid potential liabilities associated with breaches of operational safety.

The nature of the COTS challenge is that the methods to certify safety and airworthiness are difficult, if not impossible, to define in any objective way. Furthermore, the methods that might be used are likely to be expensive and time-consuming. It is necessary, therefore, to achieve consensus within the aerospace industry and regulatory agencies regarding the methods, documents, and tools to be used in the development assurance and certification processes, and the criteria and methods to verify compliance.

The results of this report are designed to be actionable including the detailed descriptions and recommendations for the issues, the roadmap for the development of COTS AEH standards and guidelines, and the structured approach for the evaluation of COTS AEH issues. The results offer a baseline for industry and regulatory action to achieve implemented solutions for current and future COTS AEH issues.

This report provides complete results and conclusions for the selected COTS AEH issues in the following structure. This provides project results and conclusions for each issue and enables rapid comparison of any subset of issues. It also provides a structured approach for the evaluation of additional COTS AEH issues.

This report is structured to provide parallel results and conclusions to allow this single document to provide documentation for each Issue. Each section 2.n contains separate reference lists and acronym/abbreviation lists for each issue and composite reference and acronym/abbreviation lists for the entire report meeting the requirement that the document be segmentable to the issue level.

Each Section 2 issue is structured to include:

2.n.1 Description of the issue,
2.n.2 Relationship to safety and certification,
2.n.3 Existing Activity,

2.n.4 Technology Weakness/deficiency,
2.n.5 Process Weakness/deficiency,
2.n.6 Recommendation / desired outcome,
2.n.7 References, and
2.n.8 Acronyms and Abbreviations.

Appendix B addresses a five step evolution of Candidate Comprehensive Guidance Documents to project implementation of standards and guidance documents required to address the COTS issues to the level of accomplished AFE 75 research.

Appendix C COTS Issues, Problems, Solutions Overview Chart provides a matrix of the following aspects of each of the selected technological issues allowing detailed comparisons:

- Identifies each Issue (Columns in the matrix and Rows for each of the following aspects)
- References each Issue in Section 2.n
- Identifies Current Standards
- Does the Standard adequately address the issue defined?
- Should a new Standard be created?
- Identifies Standard owners.
- What additional work is needed for Regulatory use?
- Summarized what additional research is needed

Appendix D: Categorizes similarities in AEH COTS issues which may inform planning for additional research.

APPENDIX A - COMPOSITE AFE 75 FINAL REPORT REFERENCES

The following list in alphabetic order lists all references used in this document and identifies the issue section (2.X) and reference number [#] in each section.

1. Accellera Systems Initiative, independent, not-for profit organization dedicated to create, support, promote, and advance system-level design, modeling, and verification standards for use by the worldwide electronics industry; www.accellera.org (accessed on 25/10/2013). 2.15[3]

2. Aeronautical Recommended Practice, ARP4761, "Appendix for Incorporation of Atmospheric Neutron Single Event Effects Analysis into Safety Assessment, AVSI Project 72 Task Group, November 29, 2011. 2.5[8]

3. AeroSpace and Defense Industries Association of Europe (ASD), http://www.asd-europe.org/, Last accessed 11/03/2013. 2.14[10]

4. Aerospace Vehicle Systems Institute AFE 72, "Incorporation of Atmospheric Neutron Single Event Effects Analysis into Safety Assessment," Draft Aerospace Information Report 219, May 16, 2012. 2.5[9]

5. Aerospace Vehicle Systems Institute, AFE 43, "Handbook for the selection and evaluation of microprocessors for airborne systems," FAA, DOT/FAA/AR-11/2, February 2011. 2.13[3], 2.21[2], 2.26[4]

6. Aerospace Vehicle Systems Institute, AFE 43 Phase 1 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-06/34, Dec 2006. 2.21[4]

7. Aerospace Vehicle Systems Institute, AFE 43 Phase 2 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-08/14, June 2008. 2.21[5]

8. Aerospace Vehicle Systems Institute, AFE 43 Phase 3 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-08/55, Feb 2009. 2.21[6]

9. Aerospace Vehicle Systems Institute, AFE 43 Phase 4 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-10/21, Sept 2010. 2.21[7]

10. Aerospace Vehicle Systems Institute, AFE 43 Phase 5 Report, "Microprocessor Evaluations for Safety-Critical, Real-Time Applications," FAA report DOT/FAA/AR-11/5, May 2011. 2.21[8]

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13. American National Standards Institute, Energy Information Administration, ANSI/EIA-933, Standard for Preparing a COTS Assembly Management Plan," August 2001. 2.1[1]

14. ANADEF, (ANAlyse de DEFaillance French Association working on electronic component failure analysis), http://www.anadef.org/lanadef.html, Last accessed 10/27/2013. 2.14[5]

15. Baker, R. Jacob, "DRAM Circuit Design, Layout, and Simulation," 3rd Edition, (IEEE Press Series on Microelectronic Systems, Wiley-IEEE, 2010. 2.4[2]

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APPENDIX B - CANDIDATE COMPREHENSIVE GUIDANCE DOCUMENT STRUCTURE

As this study was started it was recognized that it would be important to envision how the standards and guidance that were to be identified or created would be delivered to the avionics industry. The need to get the standards integrated into the development process became obvious as issues were identified and the risks that they represented were outlined. Within the study group the urgency of deployment reiterated the need for an early deployment of the standards that already exist to assist with providing consistent guidance to the industry and regulatory bodies. Some of the more obvious methods available for this delivery, such as RTCA DO-254/EUROCAE ED80, have historically taken long periods of time to get published. Therefore, alternative methods were explored and this appendix presents the methods agreed to do this in the study. The remaining alternatives that were discussed were deliberately not captured so as to reduce potential confusion and conflicts that could occur from presenting multiple options. The recommended method includes a stepped approach to aid in the early deployment of existing bodies of work and to accommodate the further development of standards to address these and other issues.

The figures illustrate a possible or recommended structure approach and are presented in the following phases:

Current Structure of Development Assurance Standards.

Step 1 Addition of COTS Standards to the Development Assurance Standards via ECMP.

Step 2 Alternative Uses of ECMP Standards.

Step 3 Addition of New COTS Standards to the Development Assurance Standards.

Step 4 Possible final step that could integrate all of the additional standards into the Development Assurance Standards.

Figures 6 through 11 illustrates a recommended structured approach and are presented in the following phases:

Figure 6 Current Structure of Development Assurance Standards shows three primary development assurance standards in use today. DO-160 is the most widely used environmental test standard. The other two documents shown are supporting documents. As noted we are assuming that ARP4761 will be updated to 4761A. It should be noted that DO-160, which is of significant use in the development of systems and hardware, is not connected to the other development assurance standards

Figure 7 Step 1 Addition of COTS Standards to the Development Assurance Standards via ECMP shows the addition of significant COTS standards to the development assurance process. These are some of the key standards identified by AFE 75 as currently available and applicable to the issues raised in this study. It suggests that these standards are able to be applied via the inclusion of ECMP standards. Also note that we are illustrating the need to connect DO-160 and the ECMP to ARP4754A. This interaction may not be practical at this time through the industry standard committees; however, the Airworthiness Authorities are considering a possible means of creating a regulatory link between the DO-160, ECMP and ARP4754A.

Figure 8 Step 2 Alternative Use of ECMP Standards shows a minor change to the industry organization of the ECMP standards and illustrates two very similar yet different standards for ECMP: SAE EIA STD 4899B and IEC/TS 62239-1. The standards owners have indicated that the standards are in review and revision processes. It appears at this time that the international standard IEC/TS 62239 will be taking on a broader role and cover more topics than the SAE EIA STD 4899. We have thus included this relationship for completeness

Figure 9 Step 3 Addition of New COTS Standards to the Development Assurance Standards projects the future evolution of standards necessary to address other issues that were identified by AFE 75 that are issues associated with COTS. It suggests that IEC/TS 62239-1 is the best vehicle for ECMP standards. The effective consistent use of these standards for addressing COTS issues is dependent upon the certification authorities recognizing these ECMP standards.

Figure 10 Step 4 Possible final step that could integrate all of the additional standards into the Development Assurance Standards suggests a possible future path to full implementation of the COTS standards. If and when DO-254/ED-80 are updated to revision A, a supplement dedicated to COTS could be created that could encompass COTS issues as a part of the relevant ECMP or directly within the supplement. Some current industry leaders believe that this should be accomplished now while others are not yet ready to open DO-254. Based on recent history with regards to opening development assurance standards and then getting the revisions published, AFE 75 believes that the identified COTS issues need to be recognized via a more urgent path. Excepting this, figure 10 may provide the final standards structure for COTS assurance management.

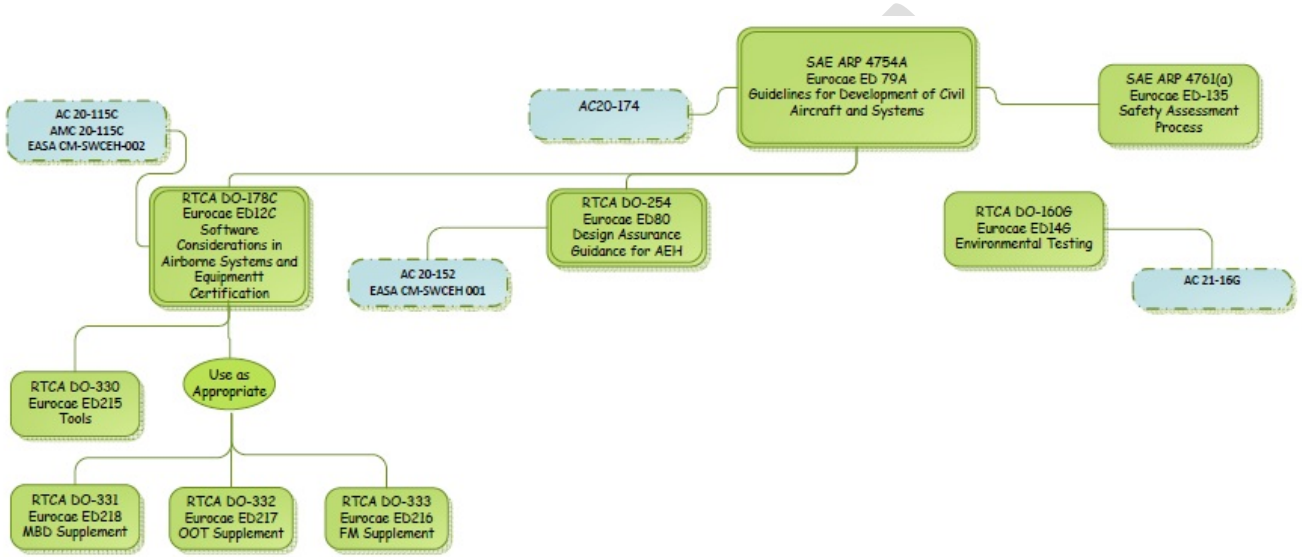

Figure 1

Current Primary
Development Assurance Standards

Assumptions:
ARP4761 will be revised to 4761a
ED-135 will be created and identical to ARP4761a

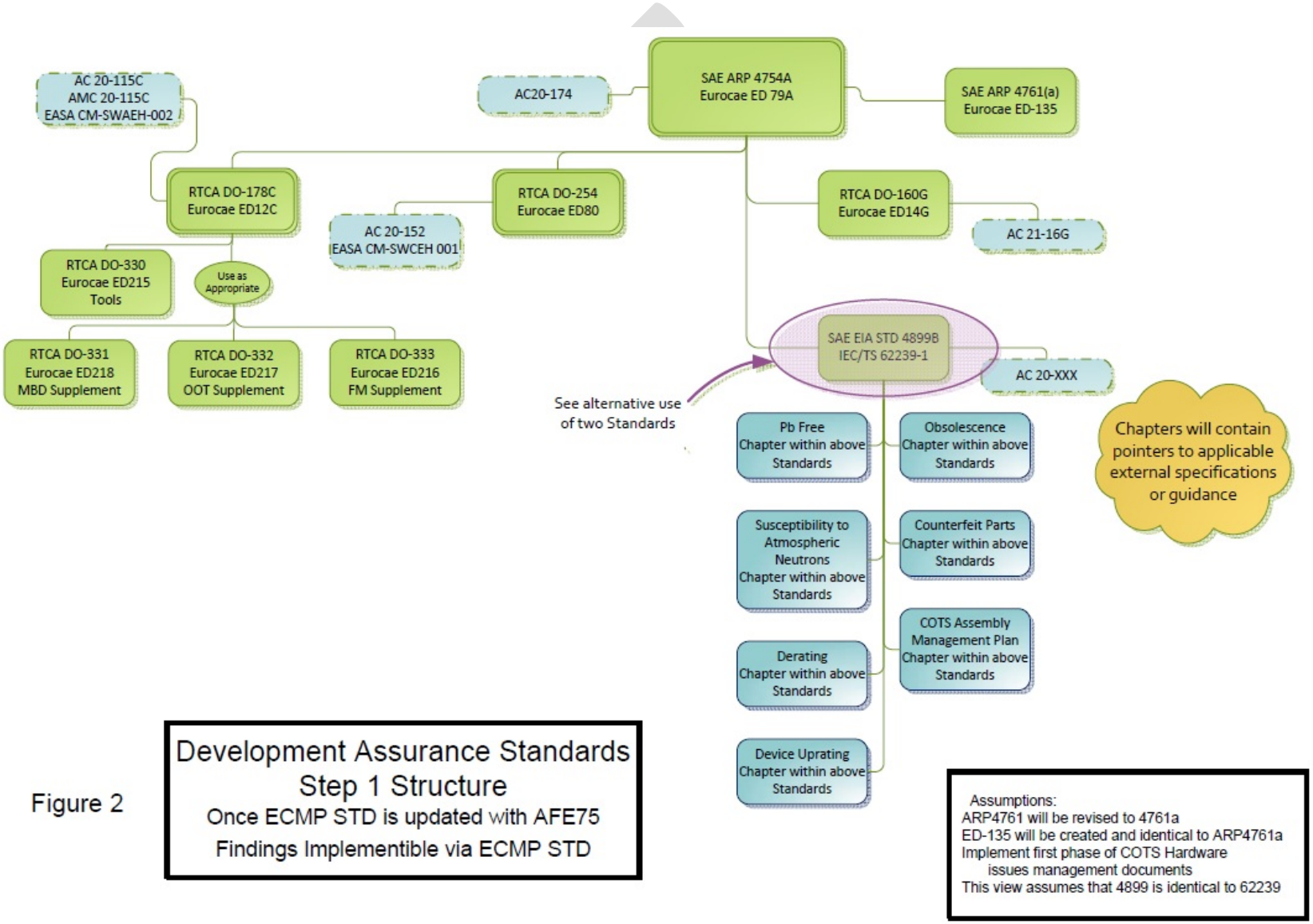

Figure 2

Development Assurance Standards
Step 1 Structure
Once ECMP STD is updated with AFE75
Findings Implementible via ECMP STD

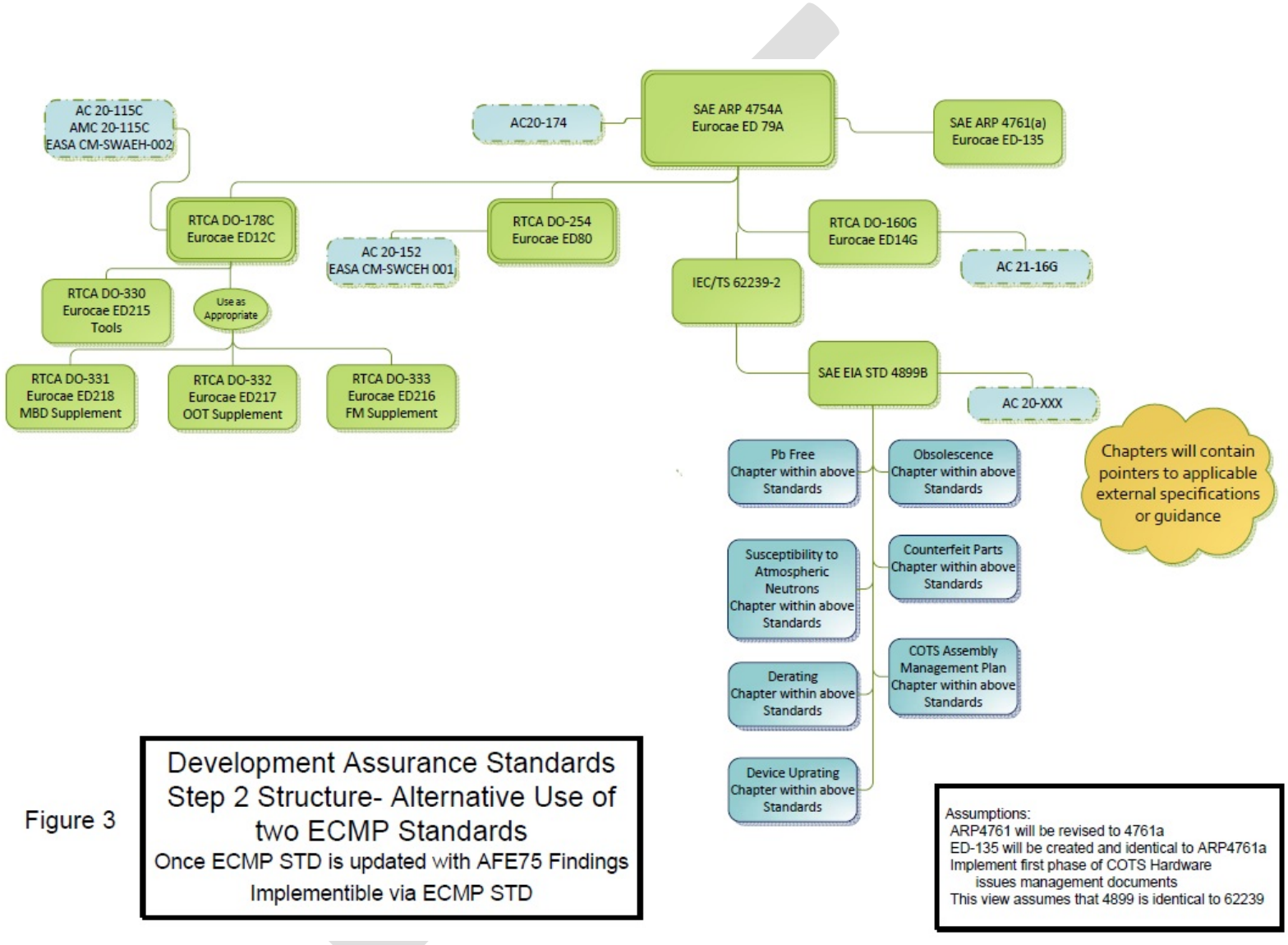

Figure 3

Development Assurance Standards Step 2 Structure- Alternative Use of two ECMP Standards

Once ECMP STD is updated with AFE75 Findings

Implementible via ECMP STD

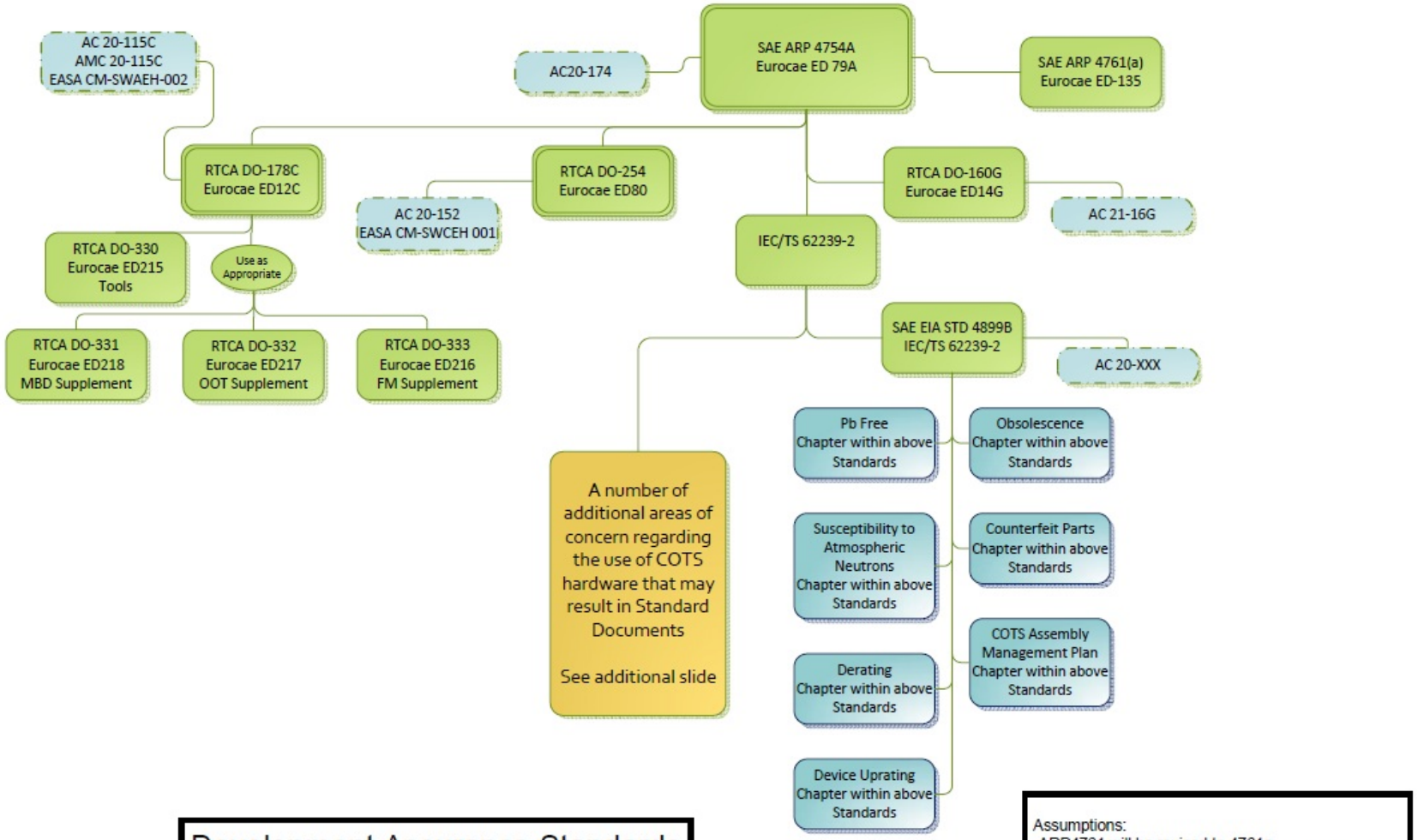

Figure 4

Development Assurance Standards Step 3 Structure

Once additional AFE75 findings on other concerns are addressed by other STDs

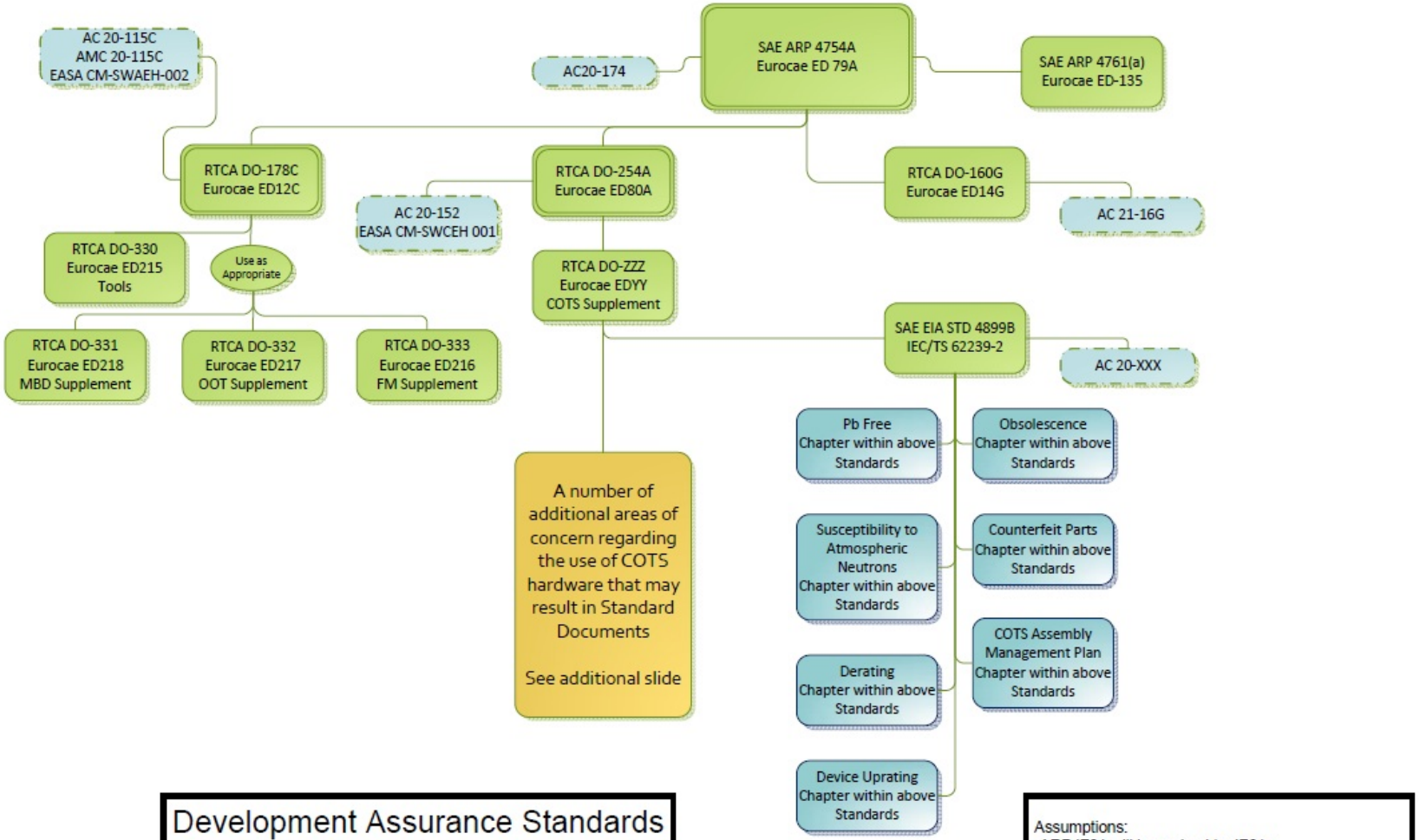

Figure 5

Electro-migration

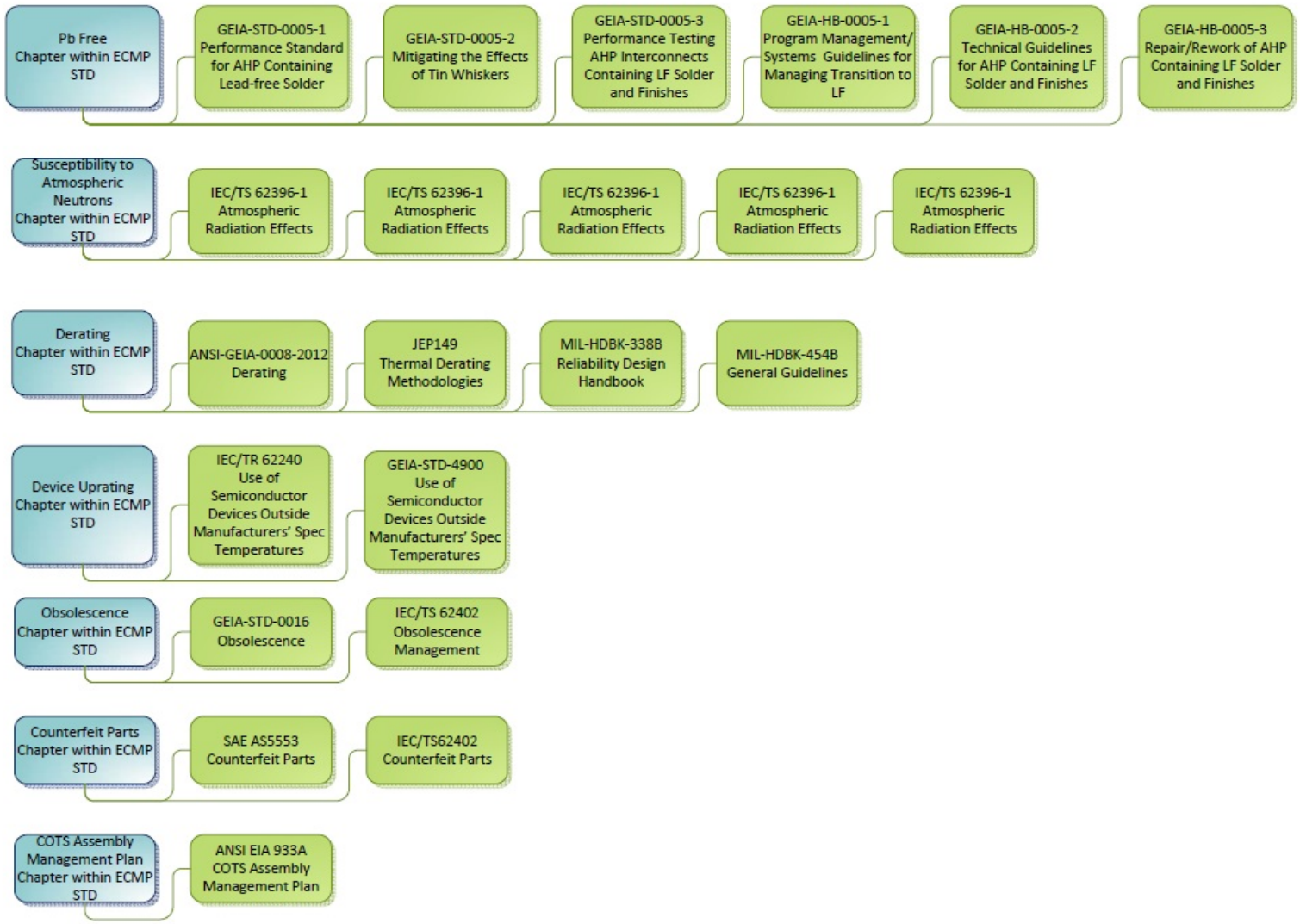

Figure 11. ECMP standard related to issue subject standards

APPENDIX C - COTS ISSUES, PROBLEMS, SOLUTIONS OVERVIEW CHART

The research was conducted to identify and define common issues, problems, and emerging solutions with the use of COTS AEH Assurance that are and/or will likely affect the industry and the regulatory.

The overview chart (Table 6) summarizes the discussions, conclusions, references, and means by which the regulatory can utilize the results of this research in a consolidated table to assist the reader with a quick grasp of the research. Section 2 was constructed to enable each individual issue section to be used as a standalone report. The overview provides the report section ID for each issue along with the issue description. The Overview Chart covers the following selected technological issues identified in the report. The Multiple, Global Electronic Supply Chain issue (2.12) was found to have no technological basis and has been omitted from the overview chart.

- COTS Assemblies
- Derating
- Sparing Reliability
- Commodity Memory
- Increased Susceptibility to Atmospheric Radiation
- Limited Life Semiconductors
- Outdated Reliability Assessment Methods
- Transition to Lead-Free Electronics
- Availability and Updates of Errata
- Counterfeit Electronic Parts
- Undocumented Features
- Usage Domain Analysis
- Production Follow-up
- Intellectual Property
- Unknown Changes
- Embedded Controllers
- Component Packaging & Monitoring Reliability
- Device Uprating
- Additional Handbook Considerations
- Obsolescence Management
- System-On-a-Chip Devices

Eight questions were considered to aid the research in filtering and determining if the issue is real and possible emerging solutions to address the issues. The questions are:

- Do any current standards exist?

- Does the standard current adequately address the issue defined?

- Does the current standard need revised?
- Does a new standard need to be created?
- Who are the standard(s) owner(s) for those standards identified with each issue?
- What additional work is needed for Regulatory use?
- Is additional research needed?
- If AFE 75 publishes this report and does nothing further will the issue be addressed?

It is recommended that the reader follows up with reading the information in the associated sections for completeness.

Table 6. COTS issues, problems and solutions overview chart

1. Issues	COTS Assemblies	Derating	Sparing Reliability	Commodity Memory	Increased Susceptibility to Atmospheric Radiation	Limited Life Semiconductors	Outdated Reliability Assessment Methods	Transition to Lead-free Electronics	Availability and Updates of Errata	Counterfeit Electronic Parts	Undocumented Features	Usage Domain Analysis	Production Follow-Up	Intellectual Property	Unknown Changes	Embedded Controllers	Component Packaging & Mounting Reliability	Device Uprating	Additional Handbook Considerations	Obsolescence Management	System-On-Chip Devices
2. Report Section References	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.13	2.14	2.15	2.16	2.17	2.19	2.20	2.21	2.22	2.26
3. Does any current standards exist?	EIA 933A	Directly usable IEC/TS62239-1 Or EIA-STD-4899 A-2009	None	None	Directly usable IEC/TS62396 Series	JESD47 IEC/TS62239-1	Loosely MIL-HB-217 SAE ARP5890 FIDES	Directly usable IEC/TS 62647 Series	None	Directly Usable AS5553 & AS6462	None	EASA CM & FAA's Handbook do address this subject but these are not standards	Directly usable IEC/TS62239-1	None	JESD46D with SAE EIA STD 4899B / IEC/TS62239-1	None	Directly usable MIL_HB_217 IPC Documents SM-785 & D-279	Directly usable IEC/TR62240	EASA CM & FAA's Handbook do address this subject but these are not standards	Directly usable IEC/TS62402 & IEC/TS62239-1 & EIA STD 0016	None
4. Does the current standard adequately address the issue defined?	No	No	N/A	N/A	Yes	No	Yes These standards are not fully adequate but they are a basis for what is commonly done. The work underway by the US DoD and AFE 80 and AFE 83 are the basis for the future.	Yes	N/A	No	N/A	N/A	Yes	N/A	Yes, But there are problems with its use	N/A	No	Yes	N/A	Yes	N/A
5. Does the current standard need revise?	ANSI EIA 933A is being revised to B	Future	N/A	N/A	N/A	Yes to IEC/TS62239-1	Revision of MIL-HDBK-217 F is being considered	Some of the current standards are being revised at this time	Revise IEC/TS62239-1 to add this issue	No	N/A	N/A	No	N/A	Yes, IEC/TS62239-1	N/A	Yes, this assumes that IPC will accept our recommendations	No	N/A	No	N/A
6. Does a new standard need to be created?	ANSI EIA 933B will be very similar to IEC/TS62239-2, Ed.1	No	Yes	Yes	AFE 72 has SAE AIR6219 and an Appx to SAE	Under Development AFE 83	Under Development in AFE 80 & AFE 83	No	No	No	Yes	Yes	No	Yes	No	Yes	No	No	Yes	No	Yes

1. Issues	COTS Assemblies	Derating	Sparing Reliability	Commodity Memory	Increased Susceptibility to Atmospheric Radiation	Limited Life Semiconductors	Outdated Reliability Assessment Methods	Transition to Lead-free Electronics	Availability and Updates of Errata	Counterfeit Electronic Parts	Undocumented Features	Usage Domain Analysis	Production Follow-Up	Intellectual Property	Unknown Changes	Embedded Controllers	Component Packaging & Mounting Reliability	Device Uprating	Additional Handbook Considerations	Obsolescence Management	System-On-Chip Devices
2. Report Section References	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.13	2.14	2.15	2.16	2.17	2.19	2.20	2.21	2.22	2.26
					ARP4761A under development																
7. Who are the standard(s) owner(s) for those standards identified with each issue	SAE & IEC	SAE & IEC	Unknown Further research will likely create a clearer possible standard owner	Unknown Further research will likely create a clearer possible standard owner	SAE & IEC	SAE & IEC	SAE	SAE & IEC	SAE & IEC	SAE	Unknown Further research will likely create a clearer possible standard owner	Possibly RTCA/EURO CAE	SAE & IEC	Possibly RTCA/Eurocae	JEDEC and IEC and APMC	Unknown Further research will likely create a clearer possible standard owner	DoD and IPC	IEC	Possibly RTCA/EURO CAE	SAE & IEC	Unknown Further research will likely create a clearer possible standard owner
8. What additional work is needed for regulatory use?	Authorities need to recognize the Standard. Via this report Industry is recommending that the standard is appropriate for Certification assurance. See Para 2.1.6	Derating is not currently required for certification. Via this report Industry is recommending that the standard is appropriate for Certification assurance.See Para 2.2.6	Not ready for authority action yet. Needs research to reference.	Not ready for authority action yet. Needs research or a standard to reference.	FAA & EASA are preparing regulatory material	Not ready for authority action yet. Needs research or a standard to reference.	AC20-157 is a starting point. This report recommends that this AC be more fully utilized until further research is completed. See Para 2.7.6	FAA & EASA enforcement of their Policy or CRI with regards to this issue. This report recommends this action be taken.See Para 2.8.6	Not ready for authority action yet. Needs a standard to reference.	This report recommends that these standards be adopted. See Para 2.10.6	Not ready for authority action yet. Needs research to reference.	Note that the documents listed in the Current Standards are not standards. For FAA to address this issue regulatory documents would need to be developed. This report recommends that this material be developed by RTCA / EUROCAE standardization bodies.See Para 2.13.6	Regulatory documents need to call for an ECMP.to support certification. This report recommends this action be taken.See Para 2.14.6	Certification Authorities Software Team is working on this.	If the referenced standard is updated to include this issue, then Regulatory call out is needed for an ECMP.to support certification. This report recommends this action be taken.See Para 2.16.6	Not ready for authority action yet. Needs research to reference.	Not ready for authority action yet.This is not ready for authority action yet because the referenced standard(s) needs to be updated.	Development of a Policy Statement regarding this issue. This report recommends this action be taken.See Para 2.20.6	Note that the documents listed in the Current Standards are not standards. For FAA to address this issue regulatory documents would need to be developed. This report recommends that this material be developed by RTCA / EUROCAE standardization bodies.See Para 2.21.6	Regulatory documents need to call for an ECMP.to support certification. This report recommends this action be taken.See Para 2.22.6	Not ready for authority action yet. Needs research to reference.

1. Issues	COTS Assemblies	Derating	Sparing Reliability	Commodity Memory	Increased Susceptibility to Atmospheric Radiation	Limited Life Semiconductors	Outdated Reliability Assessment Methods	Transition to Lead-free Electronics	Availability and Updates of Errata	Counterfeit Electronic Parts	Undocumented Features	Usage Domain Analysis	Production Follow-Up	Intellectual Property	Unknown Changes	Embedded Controllers	Component Packaging & Mounting Reliability	Device Uprating	Additional Handbook Considerations	Obsolescence Management	System-On-Chip Devices
2. Report Section References	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.13	2.14	2.15	2.16	2.17	2.19	2.20	2.21	2.22	2.26
9. Is additional research needed?	No	No	Yes, University level research that includes semiconductor industry collaboration . This could be led by AVSI. See Para 2.3.6	Yes, Type of research needs to be clarified and determination of a working group that can address this.	On going via AFE 72	On going via AFE 83	On going AFE 80/83	Yes, however this is a massive project being addressed by PERM under IPC	No	Much additional work is being conducted on this issue. Adoption of the reference standards will benefit from that research.	Yes, research that includes semiconductor industry collaboration is preferred. This could be led by AVSI. See Para 2.11.6	No	No	Yes, AFE 75 is considering a supplemental project on this See Para 2.15.6	No	Yes, Basic level research that includes semiconductor industry collaboration. This is a very large task and more thought is needed to determine a path. See Para 2.17.6	No	No	No Except for the following section: To be able to address future escalating complex systems, R&D is suggested for tools and tool suites supporting COTS integration. See Para 2.21.6.	No	Yes Basic level research that includes semiconductor industry collaboration. This is a very large task and more thought is needed to determine a path. See Para 2.26.6
10. If AFE 75 publishes this report and does nothing further will the issue be addressed?	Yes	Yes	NoSparings issue is relatively new for the avionics industry. The issue may escalate in the future when smaller process geometry components are used. The scope of the problem is still unknown, no avionics process	NoResolution of this issue requires collaboration between the semiconductor and aerospace industries. The structure of that collaboration needs to be defined for this issue and other similar issues described	Yes	Yes	YesHowever it is best led by AFE 80 and AFE 83 rather than by AFE75.	Yes	Yes	Yes	NoResolution of this issue requires collaboration between the semiconductor and aerospace industries. The structure of that collaboration needs to be defined for this issue and other similar issues described	YesEASA currently addresses this topic in their Certification Memorandum for airborne electronic hardware. EASA will therefore not remove this issue until other guidance exists taking care of it. However, the safety nets described in FAA's handbook, which is not addressed in EASA CM, will not be addressed anywhere.AFE 75 recommends the RTCA/EUROCAE associations to create new COTS	NoResolution of this issue requires collaboration between the passive component manufacturers and aerospace industries. The structure of that collaboration needs to be defined for this issue and other similar issues	Yes AFE 75 will be looking at this issue further in a supplement to this initial research. In addition, the FAA is looking at this subject as well and plans to develop guidance on IP.	Yes	NoResolution of this issue requires collaboration between the semiconductor and aerospace industries. The structure of that collaboration needs to be defined for this issue and other similar issues described	Yes, as long as IPC adopts our recommended changes.	Yes	YesEASA currently addresses parts of this issue in their Certification Memorandum for airborne electronic hardware. EASA will therefore not remove these parts until other guidance exists taking care of it. However, issues covered in FAA's handbook not	Yes	NoSystem-On-Chip Devices issue is relatively new for the avionics industry. The issue may escalate in the future when smaller process geometry components are used. The scope of the problem is still unknown,

1. Issues	COTS Assemblies	Derating	Sparing Reliability	Commodity Memory	Increased Susceptibility to Atmospheric Radiation	Limited Life Semiconductors	Outdated Reliability Assessment Methods	Transition to Lead-free Electronics	Availability and Updates of Errata	Counterfeit Electronic Parts	Undocumented Features	Usage Domain Analysis	Production Follow-Up	Intellectual Property	Unknown Changes	Embedded Controllers	Component Packaging & Mounting Reliability	Device Uprating	Additional Handbook Considerations	Obsolescence Management	System-On-Chip Devices
2. Report Section References	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.13	2.14	2.15	2.16	2.17	2.19	2.20	2.21	2.22	2.26
			Guidance exists and no other standards address this or similar topics. Therefore, this issue is at risk of not being addressed in the future.	in this report.							in this report.	guidance material to include the above issues and activities.	described in this report.			in this report.			addressed in EASA CM, will not be addressed anywhere. AF75 recommends the RTCA/EUROCAE associations to create new COTS guidance material to include the above issues and activities.		no avionics process guidance exists and no other standards address this or similar topics. Therefore, this issue is at risk of not being addressed in the future.

X

APPENDIX D – ISSUES SIMILARITY CHART BY GROUPINGS

The Issues Similarity table 7 below provides a listing of the topics and issues discussed during the research. The research started with identifying topics for consideration during Task 1. Those topics were further investigated to determine if they are items which are real issues to the industry and the regulatory. The outcome of Task 2 carried forward those topics that are believed to be issues that the industry and the regulatory face today and in the near future. The table column headers and their purpose are:

No:	Represent the section numbers assigned.
Description:	Description of the topic/issue
Docs:	Indicates that existing standards are available that partially or fully addresses the issues.
Grp#1 - #3:	Represent a grouping of issues that are considered to be similar in nature and could be collectively addressed at the same time.
Remove:	Topics that were not considered issues and were retired after Task 2 was completed.

Table 7 Issues Similarity Chart

No.	Description	Docs.	Grp #1	Grp#2	Grp #3	Remove
2.1	COTS Assemblies	X				
2.2	Derating	X				
2.3	Sparing Reliability		X			
2.4	Commodity Memory		X			
2.5	Atmospheric Radiation	X				
2.6	Limited-life Semiconductors	X				
2.7	Outdated Reliability Assessment Methods	X				
2.8	Transition to Lead-free Electronics	X				
2.9	Availability and Updates of Errata	X				
2.10	Counterfeit Electronic Parts	X				
2.11	Undocumented Features		X			
2.12	Multiple, Global Electronic Supply Chains					X
2.13	Usage Domain Analysis				X	
2.14	Production Follow-up			X		
2.15	Intellectual Property				X	
2.16	Unknown Changes			X		
2.17	Embedded Controllers				X	
2.18	Technology and Component Maturity					X
2.19	Component Packaging and Mounting Reliability	X				
2.20	Device Uprating	X				
2.21	Additional Handbook Considerations				X	
2.22	Obsolescence Management	X				
2.23	Acceptable Level of Compliance Evidence					X
2.24	Multiple Supply Chains					X
2.25	Safe Use of Complex COTS in AEH				X	
2.26	System on Chip Devices				X	